SCIENCE FOR HANDICRAFT STUDENTS

A Textbook dealing with the Scientific Principles which underlie Craftsmanship in Wood and Metal

By H. MORTON, B.Sc., A.Inst.P.
Lecturer in Science to Handicraft Students,
Mining and Technical College, Wigan

SECOND EDITION
Revised and Enlarged

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PREFACE TO THE SECOND EDITION

In its First Edition, this book was based on Section I of the syllabus in Elementary Science for the First Handicraft Teachers' Examination of the City and Guilds of London Institute. Additions have now been made so that the Second Edition includes a large proportion of Section II of the syllabus. In particular the chapters on Mechanics, Heat, Chemistry and Electricity have been enlarged and additional chapters have been included. The Second Edition should therefore serve not only for Section I of the syllabus but also for the major portion of Section II.

The scientific principles of Mechanics, Hydrostatics, Heat, Chemistry and Electricity are related to their applications in everyday life and especially to workshop practice in wood and metal. In the past, a craftsman simply used a tool but had only a vague notion of the scientific principle involved in its use. Something more than this is expected of craftsmen today, and the correlation of workshop practice and science is one of the chief features of the book.

Experiments have been included which can be performed in some cases with improvised apparatus, and in others with simple working models which can be constructed by the student. In many cases, suitable dimensions have been given and in this manner the student becomes accustomed to the making of models and to employing these models for illustrating scientific principles. Suitable exercises have been included at the end of each chapter. These include questions from the City and Guilds of London and the Union of Lancashire and Cheshire Institutes' examination papers.

The author's thanks are due to Dr. Ross, Principal of the Wigan and District Mining and Technical College, for his general interest during the preparation of the manuscript, to Dr. A. Harvey and Mr. F. Shaw for help and advice in the preparation of the manuscript, to Dr. F. Briers and Mr. E. Foley for useful suggestions on the Chemistry chapters, and to Mr. M. M. Das for reading portions of the proofs.

Thanks are also due to the following:—Messrs. Theo and Co., Ltd., for information on the Multiple Petrol Pump, Scott Greenwood and Son for tabular matter, the C.G.L.I. and the U.L.C.I. for permission to reproduce examination questions, and the Publishers for guiding the book through the press.

H. MORTON.

January, 1949.

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LIST OF DIAGRAMS

CHAPTER I

FUNDAMENTAL MEASUREMENTS

Units

Physical science is based to a large extent on exact measurement of length, mass and time. Thus, in order to express the magnitude of any measurable quantity by a number, it is necessary to decide upon a unit, which must be convenient as regards magnitude and must also be universally adopted.

Measurement of Length

The British standard of length is the yard, which is the distance between two marks on a bronze bar deposited with the Board of Trade, the bar being kept at a fixed temperature. The yard is sub-divided into three equal parts, each of which is the foot. The foot is further sub-divided into twelve equal parts, each of which is the inch.

In the Metric system the unit of length is the metre, which is the distance between the ends of a platinum rod kept at a fixed temperature and deposited in the French national archives at Sèvres. The sub-divisions and multiples of the metre are given in the following table:

10 millimetres (mm.)	=	1 centimetre (cm.).
10 centimetres	=	1 decimetre.
10 decimetres	=	1 metre.
10 metres	=	1 dekametre.
10 dekametres	=	1 hectometre.
10 hectometres	=	1 kilometre.

The connection between the metre and the yard is:

$$1 \text{ metre} = 1{\cdot}094 \text{ yards.}$$

For the measurement of length an ordinary scale may be used. This is divided into inches, with sub-divisions tenths, eighths or sixteenths, or into centimetres with sub-divisions tenths of a centimetre, i.e., millimetres.

In measuring the length of a block of wood, the following precautions must be observed.

(1) The end of the scale, being sometimes worn, must not be placed in contact with the end of the block.

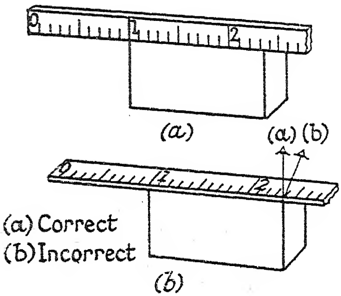


Fig. 1.

MEASUREMENT OF LENGTH BY SCALE.

(2) The scale must be placed as in Fig. 1(*a*). If placed as shown in Fig. 1(*b*), an error in measurement may be made. This error is known as parallax and is due to the eye of the observer not being in line with the end of the block.

The parallax error is illustrated by the two positions of the eye, shown in Fig. 1(*b*). If the eye is placed in the position (*a*), vertically above the end of the block, a correct reading is obtained, but in any other position, such as (*b*), an inaccurate reading is obtained.

The Calipers

When the diameter of a cylinder or sphere is required, a pair of calipers (Fig. 2) is used. The distance between the points A and B is adjusted, so that the cylinder just passes through the space between them. The distance AB is then measured by placing the scale across it.

The calipers shown in Fig. 2 are only used when an approximate measurement of the diameter is required, say to the nearest tenth or sixteenth of an inch. For very accurate measurements, where a length is required, say to $\frac{1}{100}$ of a centimetre or $\frac{1}{64}$ of an inch, the vernier calipers are used.

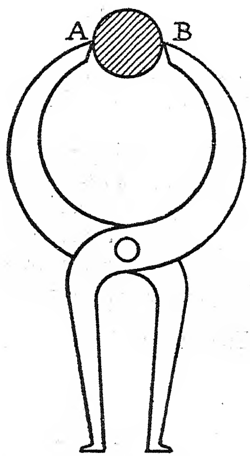


Fig. 2.

CALIPERS.

The Vernier and the Vernier Calipers

This method of measuring a length to a given fraction of the shortest division of the scale was devised by Paul Vernier. An additional scale, known as the vernier, is placed alongside the standard scale and each

division of the vernier scale bears a simple relationship to that of the standard scale. In Fig. 3(*a*), AB represents a portion of the standard scale which reads to a tenth of an inch and XY, the vernier. The object whose length is required is placed with one end in line with the zero of the standard scale and the other end in contact with X. Since 10 divisions of the vernier scale are equal to 9 divisions of the standard scale, the length of the object, given by the combination, is 5·4 inches + the fraction Jj, j being the zero mark of the vernier scale. A division line of the vernier scale coincides with a division line of the standard scale at one point only, viz. C.

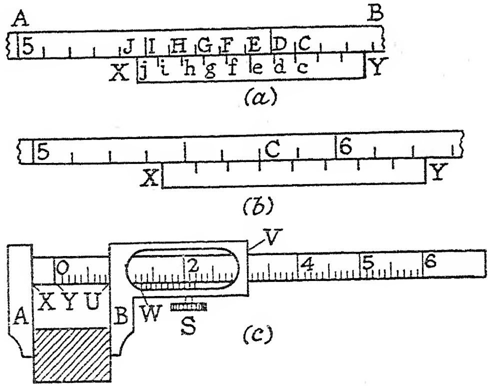


FIG. 3.
VERNIER CALIPERS.

Now 10 vernier divisions = 9 standard scale divisions ∴ 1 vernier division = $\frac{9}{10}$ standard scale division.

Hence length Dd $= (1 - \frac{9}{10}) = \frac{1}{10}$ standard scale division.
and length Ee $= 2(1 - \frac{9}{10}) = \frac{2}{10}$,, ,, ,,
and length Ff $= 3(1 - \frac{9}{10}) = \frac{3}{10}$,, ,, ,,

Hence, ultimately, the length Jj $= \frac{7}{10}$ standard scale division. Thus the reading of the standard and vernier scales is 5·4 inches + $\frac{7}{10}$ of $\frac{1}{10}$ inch = 5·47 inches.

Similarly in Fig. 3(*b*), the standard scale is divided into inches and eighths of an inch and the vernier consists of 8 equal divisions which together equal 7 divisions (eighths of an inch) of the standard scale. Since the third division line of the vernier coincides with a division line of the standard scale at C, the length measured is $5\frac{3}{8}$ inches + $\frac{3}{8}$ of $\frac{1}{8}$ inch = $5\frac{27}{64}$ inches.

A vernier slide calipers, used in practice, is shown in Fig. 3(*c*). The instrument consists of a thin steel rod upon which is etched the standard scale and to the end of which is fixed the jaw A. The slider V, with the jaw B fixed to it, has the vernier scale etched upon it and moves along the standard scale. A screw attachment S enables the slider to be fixed rigidly in position. Y and W are the zeros of the standard and vernier

scales respectively. When the jaws are closed, the point U coincides with the point X, and since UW is made equal to XY, W coincides with Y. The object, e.g., a rectangular block of wood, whose length is required, is placed within the jaws and the slider V is moved until both jaws are in contact with the object. The point where a division line of the vernier coincides with a division line of the standard scale is noted and the length of the object is given directly, viz. 1·28 inches.

The Screw Gauge

It is often necessary to measure small lengths, such as the diameter of a wire or the thickness of a sheet of metal, to a very high degree of accuracy. The instrument used in this case is known as the micrometer screw gauge. The principle on which this instrument works depends on the fact that the pitch of the screw, that is the distance between any two consecutive threads, is constant. When the screw is given a complete turn, the screw point advances a distance equal to the pitch. For example, if the pitch of the screw is $\frac{1}{10}$ inch and the screw is turned $\frac{57}{100}$ of a complete turn, then the screw point advances $\frac{57}{100}$ of $\frac{1}{10}$ inch, i.e., 0·057 inch.

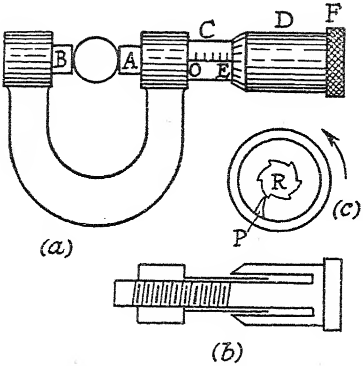


FIG. 4.

MICROMETER SCREW GAUGE.

Fig. 4(*a*) shows a screw gauge in which A and B are the jaws, C the barrel graduated in tenths of an inch and D the thimble, possessing a circular scale divided into 100 equal divisions. The thimble is connected to the screw as shown in Fig. 4(*b*). As the thimble is turned it advances along the barrel, and when the jaws are in contact with the object the reading of the circular scale opposite the line OE is noted. Thus the diameter of the ball shown in Fig. 4(*a*) can be found, e.g., $\frac{4}{10}$ inch + 28 circular divisions, i.e., 0·428 inch.

To prevent the jaws from pressing with too great a force on the object to be measured and the consequent injury to the thread of the screw, a ratchet stop F is used to rotate the thimble. When the force on the object exceeds a certain value, the pawl P slips past the ratchet R which is connected to the thimble and the screw advances no further. This is important when small thicknesses are compared (Fig. 4(*c*)).

When the jaws are in contact, the zero of the circular scale should be coincident with the line OE. But after constant use a screw gauge, particularly one with no ratchet stop, develops a zero error. In this case, the zero of the circular scale oversteps the line OE. If the zero error is 2 circular divisions and the reading of the gauge 0·257 inch, the distance measured is 0·259 inch.

The Wire Gauge

In practice the diameters of wires are usually expressed by a series of arbitrary numbers, each representing a definite diameter. There are several independent systems of numbering, of which the English Legal Standard is the most used. In this system wires are numbered from 1 to 50, but wires represented by the even numbers 2, 4, 6, etc. are most commonly used. Table I gives a few of the most important numberings. From the table it can be seen that 0·08 inch is equivalent to the standard wire gauge number 14 (S.W.G.14) and it is customary to refer to a wire of 0·08 inch diameter by the standard wire gauge number 14.

The wire gauge is generally a circular or oblong sheet of steel with slots along its rim. These slots have widths ranging from S.W.G.1 to 50, and in practice wires are drawn to this gauge.

When the diameter of a wire is required, a slot on the rim is found into which the wire just fits and the diameter is then expressed by the standard wire gauge number. The actual diameter, in millimetres or in inches, can then be determined from the table.

Table I.

Size S.W.G.	Diameter	
	Mm.	Inch
6	4·88	·192
8	4·06	·160
10	3·25	·128
12	2·64	·104
14	2·03	·080
16	1·63	·064
18	1·22	·048
20	·914	·036

The Wedge Gauge

The wedge gauge is a useful instrument for determining the internal diameter of a tube of circular bore. In Fig. 5, *a*bc represents the wedge, made of a piece of cardboard or sheet metal, the base *a*b and the side bc, which is perpendicular to *a*b, being 10 cm. and 1 cm. long respectively. The base *a*b is divided into cm. and sub-divided into mm. The wedge is placed in the tube in the manner shown with the base *a*b resting on the inside. The reading of the scale on *a*b, corresponding to the end of the tube, is noted and the diameter of the tube is calculated as follows:

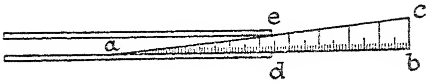


FIG. 5.
WEDGE GAUGE.

From the similar triangles *a*bc and *a*de we have:

$$\frac{de}{bc} = \frac{ad}{ab}$$

$$\therefore de = ad \times \frac{bc}{ab} = \frac{1}{10}\, ad$$

Thus if $ad = 5{\cdot}4$ cm. then $de = 0{\cdot}54$ cm., a reading which is accurate to $\frac{1}{100}$ cm.

Graduated Vessels

Fig. 6 shows a number of graduated vessels which are used for the measurement of the volumes of liquids.

The measuring cylinder, which is made of thick glass, is provided with a lip and stands on a circular glass base. A volume scale, reading in c.c., is etched on the glass. The cylinder is generally graduated upwards.

The burette consists of a glass tube, graduated downwards and supplied with a tap at the bottom. The liquid is poured into the burette to a point just above the zero mark. The tap is then opened and liquid is allowed to run through, until the surface of the liquid is level with the zero mark. In this process, any air bubbles in the exit tube are forced out. To run out, say 20 c.c. of a liquid into a vessel,the tap is opened and then closed when the surface of the liquid is level with the 20 c.c. division.

Another instrument, used for measuring an exact volume of a liquid, is the pipette, which is marked 10, 20, 25 c.c., etc., according to the volume it is intended to measure. Applying the mouth to the end A, the pipette is filled to the mark O, by suction. The thumb is placed over the

end A and then withdrawn to allow the measured volume of liquid to run into the vessel ready to receive it.

In all measuring vessels, graduated for obtaining exact volumes of a liquid, the eye must be on the same level as the lowest point of the curved

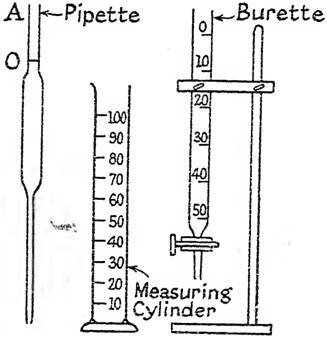


FIG. 6.

GRADUATED VESSELS.

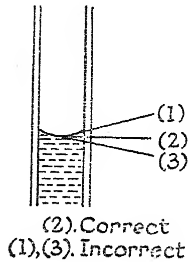


FIG. 7.

ERROR DUE TO PARALLAX.

surface (or meniscus), except in the case of mercury, when the eye must be on the same level as the highest point.

Fig. 7 serves to show how an incorrect reading may be made, if this precaution is not taken.

MASS AND WEIGHT

The mass of a body is the quantity of matter contained in the body. Since this quantity of matter remains fixed, the mass of the body does not vary.

The unit of mass in the British system is the Standard Pound, which is the quantity of matter contained in a piece of platinum, kept at the Board of Trade. In the Metric system, the unit of mass is the Standard Kilogram, which is the quantity of matter in a piece of platinum, kept by the French Government.

The relation between the two units is:—1 kilogram = 2·205 pounds.

Sir Isaac Newton, in his Law of Gravitation, stated that every body in nature attracts every other body with a force which is inversely proportional to the square of the distance between the centres of the bodies. Thus, the fact that a body released in mid air falls to the ground is due to the attractive force of the earth upon the body. This attractive force is really the weight of the body, for if we consider a body of mass

one pound, it is attracted to the earth with a force of one pound weight.

Force or weight can be measured by means of a spring balance, an account of which will now be given.

EXPERIMENT I

To find the extension of a helical spring for various loads

Construct a helical spring, 4 inches long, by winding steel wire of S.W.G. 26 round a cylindrical rod of diameter about $\frac{3}{8}$ inch, so that each turn is in contact with the preceding one. Prepare a block of wood (Fig. 8(*a*)), of dimensions 10 inches by $1\frac{1}{2}$ inches by $\frac{3}{4}$ inch, and cut a groove of rectangular section, $\frac{1}{2}$ inch wide and $\frac{1}{4}$ inch deep, parallel to the length of the block. Attach one end of the spring to the block by means of a screw A, and attach the other end to a slotted weight holder W, by means of a piece of thin string. Pass a pin, about 1 inch long, through the string at B to serve as an indicator and paste a strip of squared paper on the block to serve as a scale. Support the apparatus vertically in a stand, so that the spring is capable of moving freely in the groove, and note the reading of the indicator. Now add 0·1, 0·2, 0·3 lb., etc., in succession and note the reading of the indicator in each case. Tabulate the results and determine the extension for the various loads. Plot a graph showing the relation between the extension and the load (Fig. 8(*b*)).

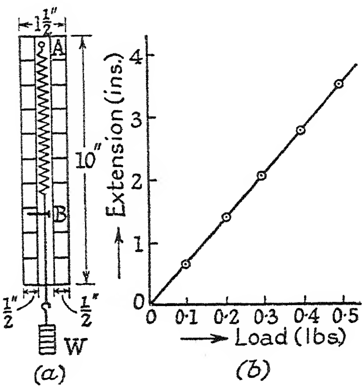


FIG. 8.

MODEL SPRING BALANCE.

Load (lbs.)	Reading of scale (inches)	Extension (inches)
0	5·5	—
0·1	6·2	0·7
0·2	6·9	1·4
0·3	7·6	2·1
0·4	8·3	2·8
0·5	9·0	3·5

The graph connecting the extension of the spring and the load is a straight line. This shows that the extension is proportional to the load.

If the weights are now indicated on the scale, the model will serve as a spring balance, by means of which an unknown weight up to 0·5 lb. may be determined.

Hooke's Law

The above experiment verifies Hooke's Law for a helical spring. Hooke's Law may be stated thus:

The extension of a helical spring is proportional to the load suspended from it.

It will be seen later that this law is only true when the load is not too great.

The Household Scales

Hooke's Law has an important practical application in the household scales (Fig. 9). A represents the iron casing which rests on the iron stand B. To the upper part of this casing, two helical springs S_1 and S_2 are attached. These springs support a steel framework C to which is attached a steel rod D which carries a scale pan E at its upper end. A portion of the rod has teeth cut along its edge and these teeth engage a small toothed wheel F which carries a pointer P. The extension of the springs is proportional to the load placed in the pan and this extension produces a proportionate rotation of the wheel F. The pointer P attached to the wheel moves round a circular scale reading in lbs. and fractions of a lb.

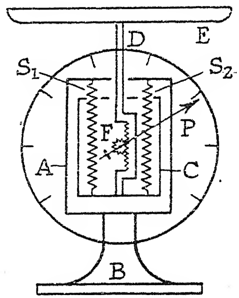


FIG. 9.
HOUSEHOLD SCALES.

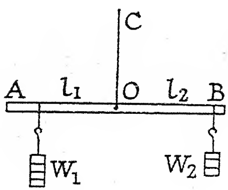


FIG. 10.
SIMPLE LEVER.

Experiment II

The Common Balance

Support a wooden rod AB (Fig. 10) about 2 feet long, 1 inch wide and $\frac{1}{2}$ inch thick, by means of a string CO, which passes through a hole in its centre. The rod will be pivoted at O and will rest in a horizontal position. Hang a weight W_1 (2 lbs.) from one arm and a different weight W_2 (1 lb.) from the other arm. Adjust the positions of the weights until the rod again rests horizontally.

Measure the distances, l_1 and l_2, between the points of suspension of the weights and the pivot O. Then calculate $W_1 l_1$ and $W_2 l_2$.

Repeat the experiment with different weights and tabulate the results as below:

W_1 lbs.	l_1 inches	$W_1 l_1$ lb. inches	W_2 lbs.	l_2 inches	$W_2 l_2$ lb. inches
2	5·5	11·0	1	11·0	11·0
1	5·3	5·3	0·5	10·5	5·25
2	4·1	8·2	1	8·2	8·2

Allowing for the errors in the experiment we may conclude that $W_1 l_1 = W_2 l_2$.

Fig. 11(*a*) shows a common balance. The balance is usually con-

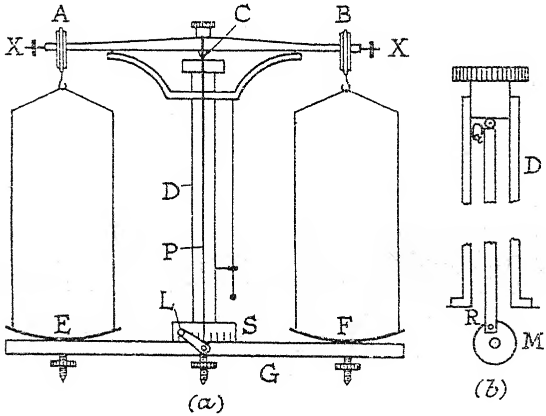


FIG. 11.
COMMON BALANCE.

structed from some material such as brass, and consists of a rigid beam, supported at its centre by an agate knife edge C which rests on an agate plane. This plane rests on a vertical support D, screwed to the wooden base G which rests on three levelling screws. The pans E and F are supported by hangers A and B which rest on knife edges, fixed to the beam. A handle L is used to raise the agate plane, so that the beam can swing freely. The handle is mounted on the same spindle as the disc M

(Fig. 11(*b*)), and a pin, attached to the end of the brass rod QR, passes through a hole in the disc. When the handle rotates in a clockwise direction the agate plane is raised above the end of the supporting tube D. A pointer P is fixed to the beam at its centre and moves along an ivory scale S. The screws XX are for fine adjustments, i.e., for making the pointer swing evenly on each side of the zero of the scale S.

The principle $W_1 \, l_1 = W_2 \, l_2$ is applied, for if the distances of the knife edges at A and B from the central knife edge C are equal, then $l_1 = l_2$ and $W_1 = W_2$.

To weigh a body, the necessary adjustments are made, the body is placed in the left hand pan and weights are added to the other pan, until the pointer swings evenly on each side of the zero, or ultimately comes to rest on the zero.

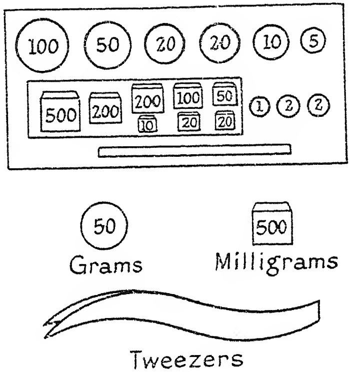


FIG. 12.
BOX OF WEIGHTS.

Fig. 12 shows a box of weights, used with the balance. The weights are arranged in order of size, viz., 100, 50, 20, 20, 10, 5, 2, 2 and 1 gram. The fractional weights, also arranged in order, are 500, 200, 200, 100, 50, 20, 20 and 10 milligrams. With each box of weights there is a pair of tweezers which are used for transferring the weights from the box to the balance pan.

Density

The density of a substance is the weight[1] per unit volume of the substance. If the weight of 10 c.c. of aluminium is 27 grams, the density of aluminium is 2·7 grams per c.c., or if the weight of 10 cubic feet of English Oak is 445 lbs., the density is 44·5 lbs. per cubic foot. Thus we have:

$$\text{Density} = \frac{\text{Weight}}{\text{Volume}}$$

In the table on p. 12, the densities of various substances, including timbers and common metals, are given. The density of a substance is an important physical constant and is often an indication of the purity of the substance. Thus if we take the case of a sample of lubricating

[1] The word "weight," when applied to density, really means "mass."

oil which has a specified density, any departure from this specification is an indication that the sample is impure.

Table II

DENSITIES OF MATERIALS

Material	Density	Material	Density
	lbs./c. ft.		gm./c.c.
Oak	44—56	Bronze	8·7—8·9
Californian redwood	20—25	Copper	8·9
Columbian pine	30—33	Aluminium	2·7
Chestnut	30—45	Emery	4·0
Sycamore	35—45	Beeswax	0·95—0·96
Cedar	31—37·5	Water	1·00
	gm./c.c.	Mercury	13·6
Mild Steel	7·7—7·9	Turpentine	0·86—0·87
Cast Iron	7·1—7·9	Lubricating Oil	0·90—0·92
Wrought Iron	7·8—7·9	Paraffin Oil	0·8
Brass	8·4—8·7	Methylated Spirits	0·83
		Linseed Oil (raw)	0·93—0·94

RELATIVE DENSITY

Consideration of Table II shows that the weights of 1 c.c. of various substances are different. Taking water as a standard of reference, the relative density (or specific gravity as it is sometimes called) of a substance

$$= \frac{\text{density of substance}}{\text{density of water}}$$

$$= \frac{\text{weight of substance}}{\text{volume of substance}} \div \frac{\text{weight of water}}{\text{volume of water}}$$

If the volumes of the substance and the water are equal we have:—

$$\text{Relative density of Substance} = \frac{\text{Weight of Substance}}{\text{Weight of an equal volume of water}}$$

Experiment III

To determine the relative density of a liquid (e.g., turpentine) by the use of a relative density bottle

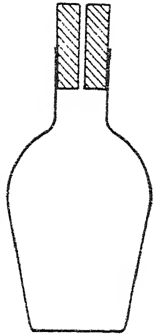


Fig. 13.
RELATIVE DENSITY BOTTLE.

The relative density or specific gravity bottle (Fig. 13) is provided with a ground stopper, which is in the form of a tube with a fine bore.

Thoroughly clean and dry the bottle and then weigh it empty. Fill the bottle to the top of the neck with water and insert the stopper. Some water overflows and some issues through the fine bore of the stopper. In this manner, the bottle is freed from air bubbles and is filled with an exact volume of water. After drying the outside, reweigh the bottle and contents. Empty the water, rinse out the bottle with a little turpentine and then fill with turpentine. After drying the outside, reweigh and enter the results as below:

(1) Wt. of bottle empty	=	22·75 gm.
(2) Wt. of bottle filled with water	=	71·89 ,,
(3) Wt. of bottle filled with liquid	=	64·52 ,,
(4) Wt. of water to fill the bottle	=	49·14 ,,
(5) Wt. of liquid to fill the bottle	=	41·77 ,,

∴ R.D. (relative density) of the liquid (turpentine) $= \frac{41{\cdot}77 \text{ gm.}}{49{\cdot}14 \text{ gm.}}$

$= 0{\cdot}85$

Experiment IV

To determine the relative density of a solid in the form of fine particles which do not dissolve in water, e.g., lead shot or sand

Weigh a clean R.D. bottle empty and weigh the bottle about one-third filled with sand. Now fill up the bottle with water and weigh again. Empty the sand and water and thoroughly clean the bottle. Refill with water and reweigh. The R.D. of the sand can be determined in the following manner:

(1) Wt. of bottle	=	22·75 gm.
(2) Wt. of bottle + sand	=	61·37 ,,
(3) Wt. of bottle + sand filled up with water	=	94·56 ,,
(4) Wt. of bottle filled with water	=	71·89 ,,

(5) Wt. of sand (2) — (1) = 38·62 ,,
(6) Wt. of water to fill the bottle (4) — (1) = 49·14 ,,
(7) Wt. of water displaced by sand (4) + (5) — (3) = 15·95 ,,

$$\therefore \text{R.D. of sand} = \frac{(5)}{(7)} = \frac{38{\cdot}62 \text{ gm.}}{15{\cdot}95 \text{ gm.}} = 2{\cdot}42$$

The relative density of substances like sand, gravel, lead shot, etc., which do not dissolve in water, can easily be obtained by the preceding method. In the case of powders, such as the various metallic salts which dissolve in water, the above method is modified. This is also the case for cement, which sets when mixed with water and cannot be removed from the bottle. In the place of water, a liquid which does not dissolve the powder is used. The weight of the liquid displaced by the powder is determined in exactly the same manner as before and, if the R.D. of this liquid has been determined by a previous experiment, the weight of water which is equal in volume to the powder can be calculated. The R.D. of the powder can then be determined.

Exercises I

1. The length of a cylinder, as determined by the use of a vernier caliper, appeared to be 3·015 inches.

Describe in detail how such a measurement would be made, and discuss possible errors:—

(*a*) due to the instrument itself,
(*b*) due to the observer.

(C. G. L. I.; Hand. S.)

2. (*a*) The circular iron diaphragm in a telephone receiver may be from nine to twelve thousandths of an inch in thickness and from 1·8 to 2 inches in diameter. Describe with all necessary detail how the thickness and diameter of a supplied specimen could be measured, or (*b*) Suggest a method for determining the internal diameter of a piece of thermometer tubing and indicate how the necessary calculations would be made.

(C. G. L. I.; Hand. S.)

3. (*a*) If you were provided with an ungraduated 25 c.c. pipette, explain how you would proceed in order to determine the correct position of the mark upon the stem.

(*b*) The weight of a 50 c.c. specific gravity bottle is found to be 23·406

grams. When filled with a certain solution, the weight was 85·214 grams. Calculate the specific gravity of the solution.

(C. G. L. I.; Hand. S.)

4. State and explain the more important principles applied in (*a*) the beam balance, (*b*) the spring balance.

Make suitable reference to the forces acting when each type of balance is in use.

(C. G. L. I.; Hand. S.)

5. A flask weighs 117·4 grams when filled to a certain mark with water. Some pieces of lead are put into the flask and the weight is then 195·8 grams. The water above the mark is then removed and the flask is found to weigh 188·8 grams. What is the volume of the lead? What is the specific gravity of the lead?

(U. L. C. I.; P. S. T.)

6. A spring is 6 inches long, but measures $8\frac{1}{4}$ inches when acted upon by a force of 10 pounds weight. What would its length be if a force of 7 pounds weight acts upon it?

Show by a full-size diagram how you would graduate a scale for the spring that would measure forces from 0 to 10 pounds weight.

(U. L. C. I.; P. S. T.)

CHAPTER II

THE PARALLELOGRAM AND TRIANGLE OF FORCES

Representation of a Force

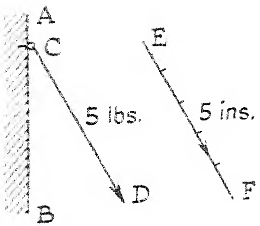


Fig. 14.

REPRESENTATION OF A FORCE.

Suppose C (Fig. 14) represents a hook in a wall AB. If a string CD is fastened to the hook and pulled with a force of 5 lbs. wt. in the direction CD, then the force in CD can be represented by the straight line EF, 5 inches long (1 inch = 1 lb. wt.) and the direction of the force is represented by the direction E to F (shown by an arrow), where EF is drawn parallel to CD. Thus a force can be represented (*a*) in magnitude, by the length of a line drawn to scale, (*b*) in direction, by the direction of the line and (*c*) in sense, by an arrow.

Resultant of two forces acting in the same straight line

If a string, fastened to a hook in a wall, is pulled by two persons A and B, A with a force of 10 lbs. wt. and B with a force of 15 lbs. wt., the combined pull is 25 lbs. wt., i.e., the sum of the individual pulls.

If a bradawl is pushed into a block of wood (Fig. 15) with a force of 80 lbs. wt. and the resistance to penetration is 75 lbs. wt., acting in the opposite direction, the combined effect of these two forces is a force of 5 lbs. wt., which produces the motion of the bradawl through the wood.

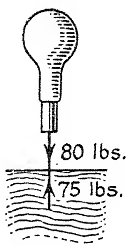


Fig. 15.

BRADAWL.

The force which has the same effect as the two individual forces is known as the resultant of the two forces. Thus the resultant of two forces, acting at a point and in the same direction, is the sum of the two forces. Also the resultant of two forces, acting at a point and in opposite directions, is the difference of the two forces, and the point of application moves in the direction of the larger force.

Experiment V

To find the resultant of two forces inclined at an angle

Figs. 16(*a*) and (*b*) show a model in front and side elevation which may be used for this experiment. Suitable dimensions are indicated in the diagram. Two uprights are fixed to a base board and these have cleats screwed to them. The cleats support a drawing board on which is pinned a sheet of drawing paper. Spring balances are suspended from the hooks A and B, fixed to the uprights. These spring

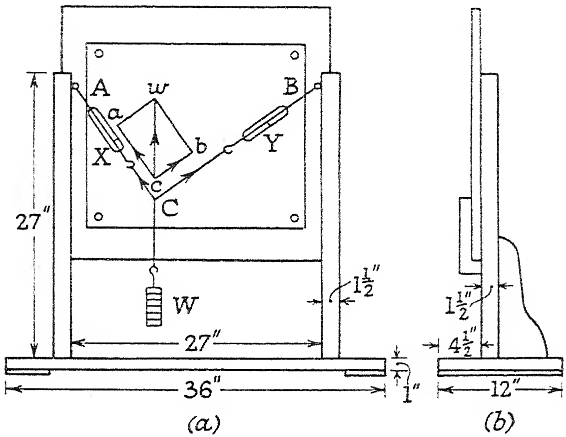


Fig. 16.
PARALLELOGRAM LAW APPARATUS.

balances are connected by a piece of fine string, and another piece of string, supporting the weight W, is attached to the point C.

To perform an experiment, mark the point c and the directions of the strings (N.B. c is shown slightly displaced). Now mark off c*a* to scale, to represent the force in the string CA (given by the balance X) and cb, also to scale, to represent the force in CB (given by the balance Y). Complete the parallelogram c*a*wb and draw the diagonal cw.

It will be found that cw represents the force W to scale and that cw is parallel to CW. But since C is at rest, the force W balances the forces in CA and CB and therefore balances the resultant of these forces. Hence the resultant of the forces represented by c*a* and cb is represented by cw.

The Parallelogram of Forces

The parallelogram law of forces states that: *if two forces acting at a point are represented in magnitude and direction by the adjacent sides of a parallelogram, the resultant of these two forces can be represented in magnitude and direction by the diagonal of the parallelogram, passing through this point.*

In Fig. 17, the forces P and Q act at O and are represented in magnitude and direction by OA and OB respectively. If OACB is the completed parallelogram, the diagonal OC represents the resultant R of the two forces in magnitude and direction.

Example. Two forces, one of 10 lbs. wt. and the other of 6 lbs. wt., act on a particle, the forces being inclined at an angle of 60° with

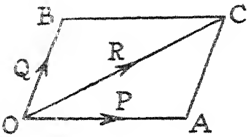


FIG. 17.
PARALLELOGRAM OF FORCES.

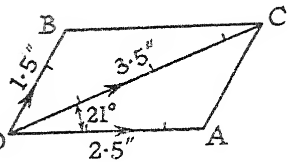


FIG. 18.
FORCE DIAGRAM FOR PARALLELOGRAM LAW.

each other. Find the magnitude of the resultant and the angle between the resultant and the larger force.

Choose the scale, 1 inch = 4 lbs. wt. Draw OA and OB equal to 2·5 inches (10 lbs. wt.) and 1·5 inches (6 lbs. wt.) respectively, at an angle of 60° with each other (Fig. 18). Complete the parallelogram OACB and draw the diagonal OC.

By measurement, OC = 3·5 inches.

$\therefore$ resultant = 3·5 × 4 = 14·0 lbs. wt.

By measurement, $\angle$COA = 21°.

Resolution of a Force into two component forces, along specified directions

In Fig. 17, the forces P and Q (represented in magnitude and direction by OA and OB respectively) have a resultant R (represented in magnitude and direction by OC).

Suppose we wish to replace the force represented by OC (Fig. 19) by two forces acting along OE and OF. Draw CA parallel to FO and cutting OE in A, and draw CB parallel to EO, cutting OF in B. Since the forces OA and OB, acting together at O, have the same effect as the force

OC, then the force OC is said to be resolved into the forces OA and OB along the directions OE and OF respectively. Each of the forces OA and OB is known as a component force.

Example. A string is fixed to a nail which is driven into a horizontal board. The string is pulled with a force of 50 lbs. wt. in a direction making an angle of 30° with the board. Find (*a*) the force tending to extract the nail, (*b*) the force tending to bend the nail.

Let DB (Fig. 20) represent the horizontal board, with the nail at O. Draw OA at an angle of 30° with OB, and draw OC at right angles to OB. If the string is pulled in the direction OB there is a tendency for the nail to be bent without extraction, whereas if pulled in the direction OC there is a tendency for the nail to be extracted without bending.

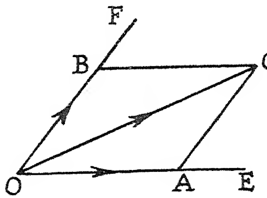


FIG. 19.

RESOLUTION OF A FORCE INTO TWO COMPONENTS.

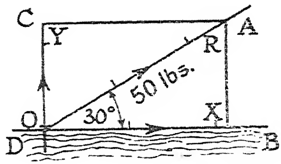


FIG. 20.

FORCE DIAGRAM FOR RESOLUTION OF A FORCE INTO TWO COMPONENTS.

Since the pull is in the direction OA, we resolve the force of 50 lbs. wt. along OB and OC.

Mark off OR to represent 50 lbs. wt. (scale 1 inch = 20 lbs. wt.). Draw RX at right angles to OB and RY at right angles to OC. Measure OX and OY, and from the chosen scale calculate the component forces.

By measurement OX = 2·15 inches.

∴ OX component, tending to bend the nail

$= 2{\cdot}15 \times 20 = 43$ lbs. wt.

Also OY = 1·25 inches.

∴ OY component, tending to extract the nail

$= 1{\cdot}25 \times 20 = 25$ lbs. wt.

THE TRIANGLE OF FORCES

Let two forces P and Q, acting at the point o, be represented in magnitude and direction by o*a* and ob respectively (Fig. 21). Complete the parallelogram o*a*cb. Then oc represents the resultant of the forces P and Q in magnitude and direction. Produce co to d, making od equal

to oc. The force R, acting at o and represented by od, balances the force represented by oc. Hence the force R balances the forces P and Q. If a small particle is placed at o, the particle will remain at rest and the forces P, Q and R are said to be in equilibrium. Also each force is the equilibrant of the other two forces.

Now consider the triangle obc shown separately. Q, P and R are represented in magnitude and direction by ob, bc and co respectively. Thus *if three forces, acting at a point, can be represented in magnitude and direction by the sides of a closed triangle taken in order, the three forces are in equilibrium.*

Or conversely, *if three forces acting at a point are in equilibrium,*

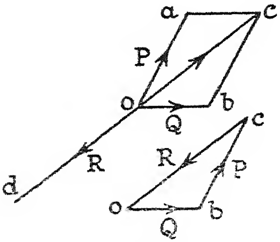


FIG. 21.

TRIANGLE OF FORCES.

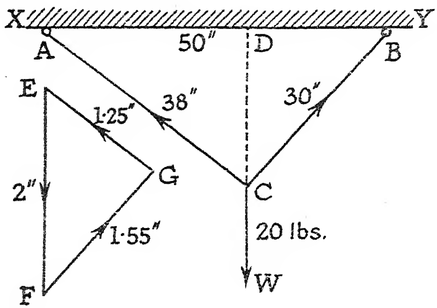


FIG. 22.

FORCE DIAGRAM FOR TRIANGLE LAW OF FORCES.

they can be represented in magnitude and direction by the sides of a closed triangle taken in order.

Example. The two ends A and B of a string are fastened to two points in a horizontal beam XY, 50″ apart. Another string from which is suspended a load of 20 lbs. wt. is fastened to the point C of the first string, so that AC and BC are 38″ and 30″ long respectively. Determine the forces in the portions AC and BC of the string.

Draw XY horizontal to represent the beam (Fig. 22). Select a point A on XY and mark off AB equal to 2·5″ (scale 1″ represents 20″). Construct the triangle ABC, with AC = 1·9″ (38″) and BC = 1·5″ (30″). Draw CW vertical to represent the direction of the load. Produce WC to cut XY in D. Now choose the scale, 1″ to represent 10 lbs. wt., and draw EF parallel to CW and equal to 2″ (20 lbs. wt.). Construct the Δ EFG with the angles EFG and FEG equal to the angles DCB and ACD respectively.

By measurement, GE = 1·25″. Hence the force in CA, acting from C to A = 1·25 × 10 = 12·5 lbs. wt.

Also FG = 1·55″. Hence the force in CB, acting from C to B = 1·55 × 10 = 15·5 lbs. wt.

Action and Reaction

If a body rests on a horizontal table, there are two forces acting on it, viz., its weight acting vertically downwards and another force, known as the reaction of the table, acting in the opposite direction. Since the body is at rest, the reaction of the table is equal to the weight of the body.

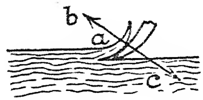


Fig. 23.
ACTION AND REACTION.

An example of action and reaction is shown in Fig. 23. The cutting edge of a chisel is advancing along the grain near the surface of a block of wood. The shaving exerts a force (viz., the resistance to bending) along *ac*, at right angles to the face of the chisel and the reaction of the face of the chisel acts along *a*b, in the opposite direction.

Tension and Compression

Fig. 24(*a*) shows a wooden rod. A force X is applied at each end parallel to its length. The forces X and X tend to increase the length of the rod. Y and Y are the equal and opposite reactions which tend to resist this increase in length, and the rod is said to be in a state of tension. Again in Fig. 24(*b*), the forces X and X tend to decrease the length of the rod, and Y and Y are the reactions which tend to resist this decrease in length. In this case the rod is in a state of compression.

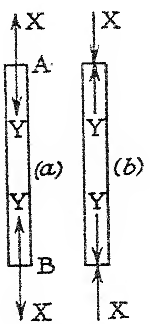


Fig. 24.
ROD (*a*) IN TENSION, (*b*) IN COMPRESSION.

The Jib Crane

Fig. 25 represents a model of a jib crane. AC is the jib, which is hinged to the vertical post AB at A. BC is the tie rod, hinged to the vertical post at B and to the jib at C. The load W is suspended from a hook at C. The jib and the tie rod are in a state of compression and tension respectively. The force in the jib is given by the compression balance X and that in the tie rod, by the extension balance Y.

Considering the equilibrium of the point C, we have: the weight W acting vertically downwards, the force P acting along AC, and the force Q acting along CB.

If FE is drawn to scale to represent the weight W in magnitude and

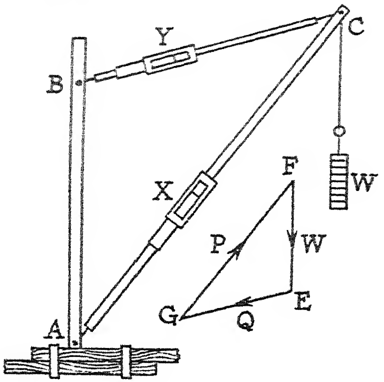


FIG. 25.
JIB CRANE.

direction, and EG and GF are drawn parallel to BC and AC respectively, then EG and GF represent the forces in CB and AC respectively, in magnitude and direction.

Exercises II

1. Define the "Resultant of Forces."

Find graphically the magnitude and direction of the resultant of 2 forces of 85·6 lbs. and 34·8 lbs. respectively which act at an angle of 60°.

(U. L. C. I.; P. S. T.)

2. Find by drawing, the magnitude and direction of the resultant of two forces of 38 and 56 lbs. respectively acting at a point at an angle of 45°.

Explain how you would check your result by experiment.

(U. L. C. I.; P. S. T.)

3. A cord $6\frac{1}{2}$ ft. long is attached at its two ends to two nails placed 5 ft. apart in a horizontal line on a vertical wall. An 8 lb. weight is suspended by a second cord, which is knotted to the first at a point 3 ft. from one end. Explain how the pull on each of the cords can be

determined by a graphical method. Illustrate your answer by means of a drawing to scale.

(C. G. L. I.; Hand. S.)

4. In a model crane the length of the jib BC is 20″, and the length of the tie AC is 35″; the base AB is horizontal and is 18″ long. Determine the force in the jib and tie when a weight of 10 lbs. hangs on the jib hook.

5. A string is attached to a nail driven into a vertical wall. The string is pulled with a force of 80 lbs. wt. in a direction making an angle of 30° with the wall. Determine the magnitude of the force (*a*) tending to draw the nail, (*b*) tending to bend the nail.

CHAPTER III

MOMENTS

MOMENTS

In Experiment II it was seen that a weight W_1 balanced another weight W_2, even though W_1 was greater than W_2. The smaller weight was placed further away from the pivot than the larger one, in order that their turning effects should be equal. This turning effect, or moment as we shall call it, depends partly on the weight and partly on its distance from the pivot. Thus the moment of a force about a

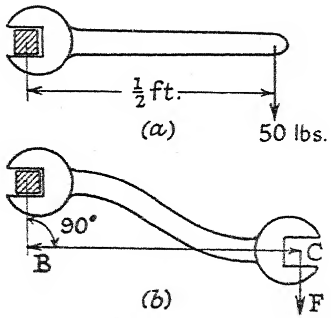


FIG. 26.

SPANNER.

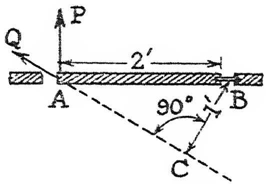


FIG. 27.

TRAP DOOR.

fixed point may be defined as the product of the force and the perpendicular distance of the force from the point.

$$\text{i.e., Moment} = \text{Force} \times \text{Distance.}$$
$$= F \times d.$$

As an example, consider the spanner (Fig. 26(*a*)), used for screwing nuts on to bolts. The force is applied near the end of the spanner at right angles to its length. If the distance from the centre of the nut to the point of application of a force of 50 lbs. wt. is ½ foot, then the turning moment is equal to 50 lbs. × ½ ft., i.e., 25 lbs. ft.

In the case of the spanner, shown in Fig. 26(*b*), which is used when the nut is inaccessible to a straight spanner, the force F is applied at

right angles to the line BC and the moment of the force is equal to F $\times$ BC.

Let us consider the case of the trap door shown in Fig. 27. The door is more easily lifted by applying the force at right angles to the door, i.e., along AP, than along AQ. If a force of 30 lbs. wt. is applied along AP, then the moment of this force about B is 30 $\times$ 2 lbs. ft. But if a force of 30 lbs. wt. is applied along AQ, the moment is 30 $\times$ 1 lb. ft.

Thus the maximum moment is obtained by applying the force at right angles to the door.

Many other examples will come to the mind of the student. Thus in the case of the vice handle, to obtain maximum turning effect the force must be applied at right angles to the handle and also as near the end as possible.

A moment may be either clockwise or counter-clockwise. In Fig. 10 we may consider the pivot O to represent the centre of a clock face. The weight W_2 tends to turn the beam in the direction in which the hands of a clock move and thus exerts a clockwise moment about O. The weight W_1 tends to turn the beam in a counter-clockwise direction and therefore exerts a counter-clockwise moment.

Experiment VI

The Principle of Moments

A model which may be used in this experiment is shown in Figs. 28(*a*) and (*b*). The model is shown in front and side elevation and can be constructed by the student.

E is a flat wooden disc, $\frac{1}{2}$ inch thick and 12 inches in diameter, with a piece of steel piping, $\frac{1}{4}$ inch in internal diameter, fitting rigidly through its centre. The disc contains a series of holes into which small wooden pegs may be inserted. A steel bolt N, $3\frac{1}{2}$ inches long and $\frac{3}{16}$ inch in diameter, which serves as a pivot for the disc, passes through the front support AB and is secured by a nut at the back of the upright CD. (N.B. It is essential that the piping should pass through the exact centre of the disc. The disc will then come to rest in any desired position, when no weights are suspended from the pegs.)

XY is a boxwood inch scale, reading in tenths of an inch, and fixed at right angles to the wooden support CD. A plumb bob P is suspended from a hook F, fixed vertically below the centre of the disc. W_1, W_2, etc., are sets of slotted weights, each of $\frac{1}{10}$ lb. In order to keep the disc in a vertical plane when weights are suspended from the pegs, a small guide pulley G, $\frac{3}{8}$ inch in diameter, is fixed to the support CD. To perform an

experiment, weights are hung from the pegs, e.g., two on each side of the pivot, and the disc takes up a position of equilibrium. The moment of the force W_1, about the pivot N, is the product of the force W_1 and the perpendicular distance of the force from the pivot, i.e., $W_1 \times$ distance between the strings supporting W_1 and P. The moment of each

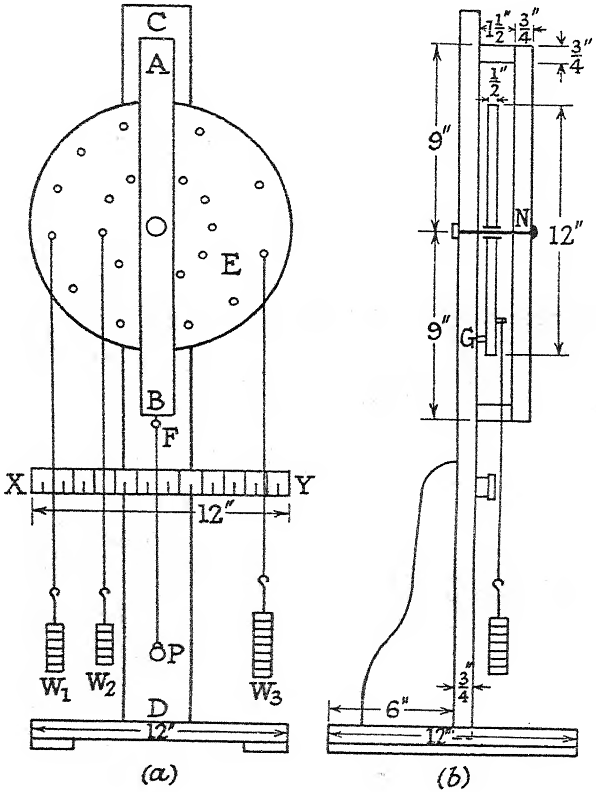


FIG. 28.

APPARATUS FOR VERIFYING THE PRINCIPLE OF MOMENTS.

of the other forces about the pivot is determined in the same manner. The sum of the clockwise moments is then compared with the sum of the counter-clockwise moments.

The results obtained may be tabulated as follows:—

Sum of Clockwise Moments	Sum of Counter-clockwise Moments
0·3 (lb.) × 5·2 (ins.) + 0·9 (lb.) × 2·6 (ins.) = 1·56 (lb. ins.) + 2·34 (lb. ins.) = 3·90 (lb. ins.)	0·4 (lb.) × 4·5 (ins.) + 1 (lb.) × 2·1 (ins.) = 1·8 (lb. ins.) + 2·1 (lb. ins.) = 3·90 (lb. ins.)
0·5 (lb.) × 2 (ins.) + 0·8 (lb.) × 5·2 (ins.) = 1·0 (lb. ins.) + 4·16 (lb. ins.) = 5·16 (lb. ins.)	0·5 (lb.) × 5·2 (ins.) + 0·9 (lb.) × 2·9 (ins.) = 2·6 (lb. ins.) + 2·61 (lb. ins.) = 5·21 (lb. ins.)

The experiment shows that the sum of the clockwise moments about the pivot is approximately equal to the sum of the counter-clockwise moments.

The above conclusion is embodied in the law known as the Principle of Moments, which states that: *if a number of coplanar forces keep a body in equilibrium, the sum of the clockwise moments about any point in the plane is equal to the sum of the counter-clockwise moments about the same point.*

Experiment VII

Prepare a wooden rod AB, of approximate dimensions 2′ by 1″ by $\frac{1}{2}$″, and find its weight by means of a spring balance, reading to 7 lbs. in eighths of a lb. Support the rod by means of two strings (Fig. 29), attached to the spring balances X and Y (each reading to 7 lbs. in eighths of a lb.) which are suspended from two iron stands. Suspend weights of 2 lbs. and 4 lbs. from the rod by means of strings looped over the rod. Adjust the supporting strings until they are vertical. Now find the sum of the downward forces acting on the rod (i.e., the sum of the two hanging weights and the weight of the rod). Also find the sum of the upward forces (i.e., the sum of

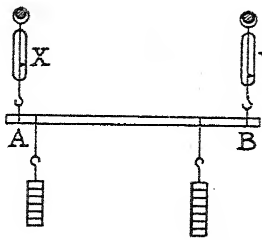


Fig. 29.

BALANCED BEAM.

the readings given by the balances). Repeat the experiment for different weights and tabulate the results as follows:

Sum of Upward Forces (lbs. wt.)	Sum of Downward Forces (lbs. wt.)
$3\frac{3}{8} + 3\frac{1}{8} = 6\frac{1}{2}$	$2 + 4 + \frac{1}{2} = 6\frac{1}{2}$
$5\frac{1}{4} + 3\frac{1}{4} = 8\frac{1}{2}$	$4 + 4 + \frac{1}{2} = 8\frac{1}{2}$

The experiment shows that the sum of the upward forces is equal to the sum of the downward forces in the case of a rod, at rest, under a system of vertical forces.

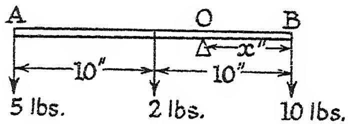


FIG. 30.

BEAM BALANCED AT A POINT.

Example. A uniform rod AB, 20 inches long and weighing 2 lbs., has weights of 5 lbs. and 10 lbs. hung from the ends A and B respectively. About which point will the rod balance? (The weight of the rod acts vertically downwards through its centre. See p. 37.)

Suppose the rod balances about the pivot O, x inches from the end B (Fig. 30). Taking moments about O, we have:

Sum of Clockwise moments = Sum of Counter-clockwise moments.

$$10x \text{ lb. ins.} = 2(10 - x) \text{ lb. ins.} + 5(20 - x) \text{ lb. ins.}$$
$$\therefore 10x = 20 - 2x + 100 - 5x$$
$$\therefore 17x = 120$$
$$\therefore x = \frac{120}{17} \text{ ins.}$$
$$\therefore x = 7{\cdot}06 \text{ ins.}$$

REACTIONS AT THE SUPPORTS OF BEAMS

By using the results of Experiments VI and VII, it is possible to calculate the upward forces or the reactions at the supports of a loaded beam. The following example serves to show how this is done.

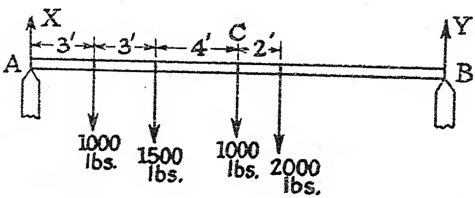


FIG. 31.

REACTIONS AT THE SUPPORTS OF A LOADED BEAM.

Example. A uniform girder AB, 20 ft. long and weighing 1,000 lbs., is supported hori-

zontally by two pillars, one at each end. Vertical loads of 1,000 lbs., 1,500 lbs. and 2,000 lbs. are placed at points 3, 6 and 12 ft. respectively from the end A. Find the reactions of the supports (Fig. 31).

The weight of the beam acts vertically downwards through its centre C. (See Centre of Gravity.)

Let X and Y be the upward forces at A and B respectively. Taking moments about A, for the equilibrium of the girder,

Sum of Clockwise moments = Sum of Counter-clockwise moments.

$$20Y \text{ (lb. ins.)} = 1{,}000 \times 3 \text{ (lb. ins.)} + 1{,}500 \times 6 \text{ (lb. ins.)} + 1{,}000 \times 10 \text{ (lb. ins.)} + 2{,}000 \times 12 \text{ (lb. ins.)}$$

$$\therefore 20Y = 3{,}000 + 9{,}000 + 10{,}000 + 24{,}000$$

(N.B. The moment of the force X about A is zero.)

$$\therefore 20Y = 46{,}000$$

$$\therefore Y = 2{,}300 \text{ lbs.}$$

But Sum of the upward forces = Sum of the downward forces.

$$\text{i.e., } X + Y = 1{,}000 + 1{,}500 + 1{,}000 + 2{,}000$$

$$\therefore X + 2{,}300 = 5{,}500$$

$$\therefore X = 5{,}500 - 2{,}300 = 3{,}200 \text{ lbs.}$$

Levers

A lever is a rigid bar which can be rotated freely about a fixed point, called the fulcrum. In Fig. 32, AB represents a lever which turns about the fulcrum F. The load W is applied at the end B and the effort P, required to overcome this load, is applied at the end A. From the Principle of Moments, we have:—

$$Wb = Pa.$$

It will be noticed that the fulcrum is between the effort and the load, and the lever in this case is known as a lever of the first class.

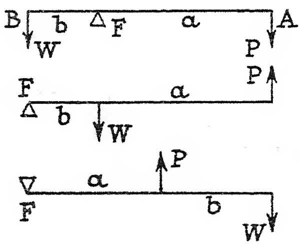


Fig. 32.
LEVERS.

Two other levers, viz., a second and a third class lever, are shown in the diagram. In the second class lever the fulcrum is at one end, the effort P is applied at the other end and the load W is between the effort and the fulcrum.

In the third class lever the fulcrum is at one end, the load W is at

the other end and the effort P is applied between the load and the fulcrum. In each case, we have:—

$$Pa = Wb.$$

The Bent Lever

Sometimes the arms of a lever are inclined at an angle. This type of lever, one of which is shown in Fig. 33, is called a bent lever. O is the fulcrum or pivot and the effort P and the resistance W are applied at the ends A and B respectively. These forces are generally applied at right angles to the arms of the lever.

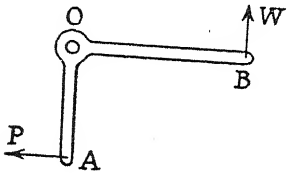


FIG. 33.
BENT LEVER.

In this case, we have:—

$$P.AO = W.BO.$$

Examples of the first class of levers are the claw hammer, pincers, wire cutters, bow saw, etc.

The Claw Hammer

Fig. 34 represents the claw hammer, which is used for extracting nails from blocks of wood. In the position shown the point O of the head acts as the fulcrum and the resistance to extraction R represents the load. The effort P is applied at right angles to the handle. From the diagram, it will be seen that:—

$$Pa = Rb.$$

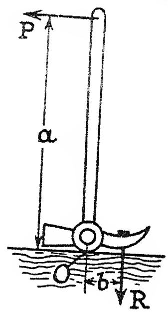


FIG. 34.
CLAW HAMMER.

The Wire Cutters

The wire cutters (Fig. 35) are an example of a double lever of the first class. If we consider the handle A to be at rest, then R represents the resistance exerted by the wire to the lower cutting edge and P the effort applied at a point near the end of the handle B. Taking moments about the pivot O, we have:—

$$Pa = Rb.$$

Similar examples of the double lever of the first class are the scissors, the pincers used for gripping a nail, the rivet tongs, etc.

Example. Fig. 36 shows a pair of pincers, held in the hand so as to grip a nail, driven into a block of wood which is held rigidly in a vice. A piece of sheet metal, the edge of which acts as a pivot, is rigidly fixed

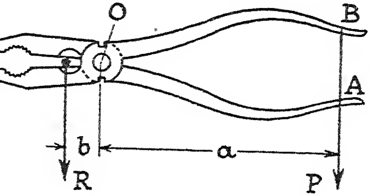


FIG. 35.
WIRE CUTTERS.

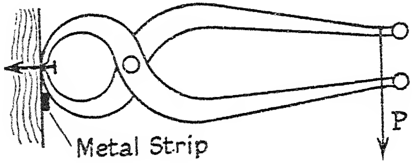


FIG. 36.
PAIR OF PINCERS.

to the block of wood. If the distance of the pivot from the nail is $\frac{1}{2}$ inch and the resistance to extraction 400 lbs. wt., determine the effort, applied at right angles to the pincers and at a distance of 6 inches from the jaws, which will withdraw the nail.

Taking moments about the pivot, we have:—

$$P(\text{lbs. wt.}) \times 6(\text{inches}) = 400(\text{lbs. wt.}) \times \tfrac{1}{2}(\text{inch})$$

$$\therefore P = \frac{400(\text{lbs. wt.}) \times \frac{1}{2}(\text{inch})}{6(\text{inches})} = 33{\cdot}3 \text{ lbs. wt.}$$

THE BOW SAW

The bow saw, which is used for cutting curves in thin sheets of wood, is another example of a double lever of the first class. Since the blade is very thin, it must be kept in tension with a considerable force. In Fig. 37, BD represents the thin blade and AB and CD represent two levers, capable of turning about the pivots X and Y respectively, at the ends of the support Z. E is a twisted cord attached to the ends A and C of the levers. If the twist of the string E is increased by turning the rod R, the length of the string decreases, with a consequent increase of the tension. Thus the tension in the thin blade BD will be increased to such a value, that the required stiffness is produced.

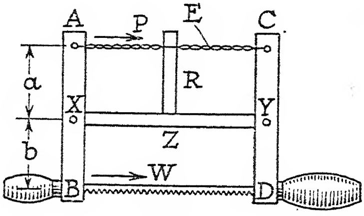


FIG. 37.
BOW SAW.

Taking moments about X (or Y) we have:—

$Pa = Wb$, where P is the tension in the twisted string, W the tension in the blade, and a and b the distances of the string and the blade from XY respectively.

The Belt Lever

The belt lever is an example of the second class of levers. In workshops containing a number of lathes, it is necessary to have a means of stopping any lathe without disturbing the running of the others. This is done by an arrangement shown in Fig. 38. AB represents the main shaft, with the pulley X fixed to it, and CD the countershaft, to which the pulley Z is fixed. Any rotation of this pulley causes the countershaft to rotate. On the other hand, Y is a pulley which rotates freely on the countershaft. If the main shaft AB is rotating, the belt connecting X and Y simply rotates the pulley Y and not the countershaft CD. If, however, the belt is transferred to the fixed pulley Z, the countershaft rotates. This rotation is then transmitted to the lathe spindle EF by the belt connecting the speed cones U and W (see Chapter VII).

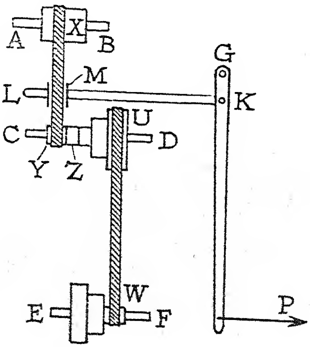


Fig. 38.
BELT LEVER.

A lever pivoted at G is used for transferring the belt from Y to Z. A wooden cross piece KL is hinged at K to the lever and a fork M which encloses the belt is attached to the cross piece. In order to start the lathe, the belt must be transferred from Y to Z and the effort P must be applied from left to right, as shown in the figure. The resistance of the belt to being moved acts along KL.

The hand lever of a force pump is another example of the second class of levers, exactly similar in principle.

The Action of the Connecting Rod on the Flywheel of an Engine

The action of the connecting rod on the crank of a flywheel in a steam engine is an example of the third class of levers. In Fig. 39, A represents the piston and B the piston rod, connected to the movable cross head C. The connecting rod R is fastened by means of pins, at one end to the

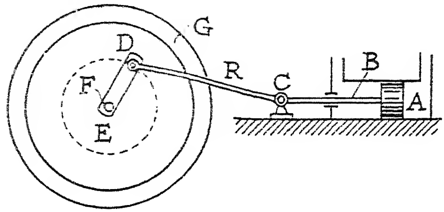


FIG. 39.
FLYWHEEL OF A STEAM ENGINE.

cross head, and at the other end to the crank ED. The crank and fly-wheel are mounted on the same shaft F. The mass of the flywheel may be considered to be concentrated at the rim and its resistance to being set in motion may be considered to act at G. The effort is the force exerted by the connecting rod on the crank at the end D, and F is the fulcrum.

COMPOUND LEVERS—THE WEIGHING MACHINE

Fig. 40 shows the system of levers in a common type of weighing machine. The lower lever L, shaped like a letter U, has knife edges A and B which rest on two V supports and chains PQ and RS connect the points P and R of the lever L to the cross bar on the Y-shaped lever M. This lever has two knife edges C and D which rest on the V supports shown in the diagram and the other end I is connected by a light rod to the end J of a simple lever N which is pivoted at R. For stability, the weighing table rests on four legs, one at each corner. Two of these legs rest on the knife edges E and F on the lever L and the other two legs rest on the knife edges G and H, attached to the lever M. A small weight w, placed on the end K of the lever N, balances the load W which is placed on the centre of the weighing table. This load may be considered to be equivalent to a load of W/4 acting vertically downwards at each corner of the table.

Let the load on the table be 1,000 lbs. and suppose T_1 is the combined tension in the chains PQ and RS. Also suppose AE and BF each equal 2 inches and the perpendicular distance between PR and the line AB equals 15 inches. Then

$$2 \times \frac{1{,}000}{4} \times 2 \text{ lb. ins.} = T_1 \times 15 \text{ lb. ins.}$$

$$\therefore T_1 = \frac{1{,}000}{15} \text{ lbs.}$$

Let the horizontal distance between I and the line joining C and D be 18 inches and the horizontal distance between QS and CD be 6 inches. Also let GC and HD be each equal to 2 inches. Then, if T_2 is the tension in the rod IJ, we have:

$$T_2 \times 18 \text{ lb. ins.} = \frac{2 \times 1{,}000}{4} \times 2 \text{ lb. ins.} + \frac{1{,}000}{15} \times 6 \text{ lb. ins.}$$

$$\therefore T_2 = \frac{1{,}000 + 400}{18} \text{ lbs.}$$

$$= \frac{1{,}400}{18} \text{ lbs.}$$

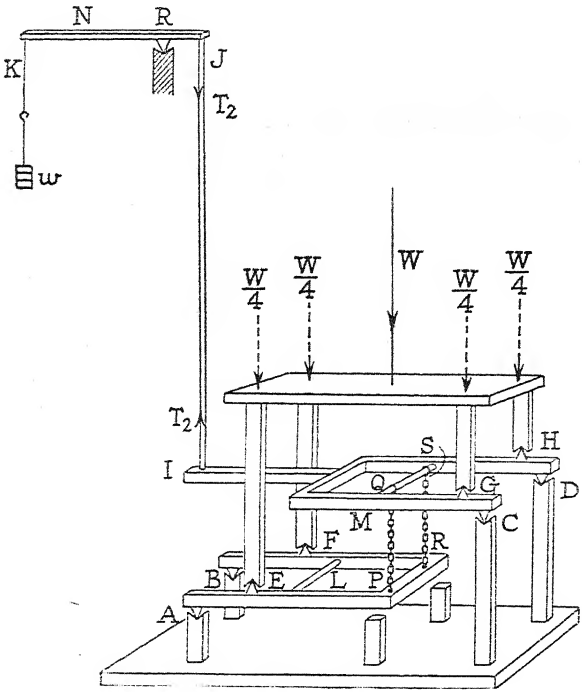


FIG. 40.
WEIGHING MACHINE.

Now if RJ and KR are 2 inches and 10 inches long respectively, we have:

$$w \times 10 \text{ lb. ins.} = \frac{1{,}400}{18} \times 2 \text{ lb. ins.}$$

$$\therefore w = \frac{1{,}400 \times 2}{18 \times 10} \text{ lbs.}$$

$$= 15{\cdot}55 \text{ lbs.}$$

i.e., a weight of 15·55 lbs. placed at K balances a load of 1,000 lbs. placed on the platform.

Parallel Forces and Couples

Parallel forces are said to be like when they act in the same direction and unlike when they act in opposite directions. Fig. 41(*a*) shows two like parallel forces P and Q, separated by a distance AB, while Fig. 41(*b*) shows two unlike parallel forces R and S, separated by a distance CD.

When two unlike parallel forces separated by a distance are equal,

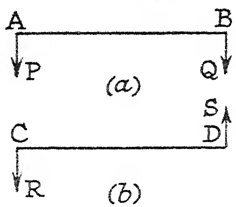


Fig. 41.

PARALLEL FORCES AND COUPLE.

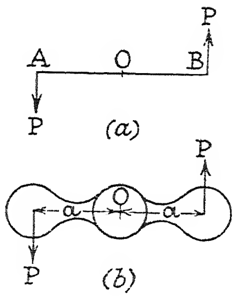


Fig. 42.

ACTION OF A TAP.

they constitute a couple. In Fig. 42(*a*), we have two unlike parallel forces, each equal to P, and the moment of the couple about a point O is:—

$$\begin{aligned} & P.\ OB + P.\ OA \\ & = P.\ AB \end{aligned}$$

= One force × the perpendicular distance between the forces.

In many practical applications the point O, about which the two forces have their turning effects, is midway between the forces. This is the case in the action of a tap, shown in Fig. 42(*b*). The axis of rotation of the tap is through O, at right angles to the plane of the paper. Equal and opposite forces P are applied at a distance a from O and the moment of the couple is $P \times 2a$.

Other examples of couples, which will readily come to the mind of the student, are the actions of the steering wheel of a car, the twist gimlet, the stock and die used in cutting screw threads on cylindrical rods (Fig. 66), and the wrench and tap used for cutting threads on the inside of cylindrical tubes.

TO FIND THE MAGNITUDE AND LINE OF ACTION OF A NUMBER OF PARALLEL FORCES

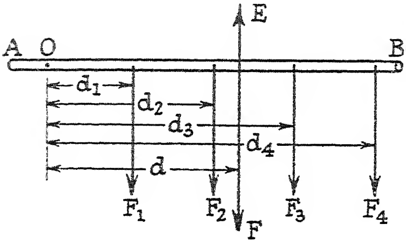


FIG. 43.
RESULTANT OF PARALLEL FORCES.

Suppose a number of forces F_1, F_2, F_3, F_4, etc., act on a light horizontal rod AB, at distances d_1, d_2, d_3, d_4, etc., respectively, from some point O (Fig. 43). To maintain the rod in equilibrium an upward force E (known as the equilibrant) must be applied at some point at a distance d from O.

Taking moments about the point O, we have:—

Sum of Clockwise moments = Sum of Counter-clockwise moments.

$$\text{i.e., } E \times d = F_1d_1 + F_2d_2 + F_3d_3 + F_4d_4, \text{ etc.}$$
$$\text{also } E = F_1 + F_2 + F_3 + F_4 + \ldots$$

But the resultant F of the forces F_1, F_2 F_3, etc., is equal and opposite to the equilibrant E.

$$\text{Hence } F = F_1 + F_2 + F_3 + \ldots$$
$$\text{and } Fd = F_1d_1 + F_2d_2 + F_3d_3 + \ldots$$

i.e., *the moment of the resultant force about any point is equal to the sum of the moments of the component forces about the same point.*

Example. In Fig. 43, F_1, F_2, F_3 and F_4 are 2, 4, 6 and 8 lbs. respectively and the distances d_1, d_2, d_3 and d_4 from the point O are 6, 8, 12 and 15 ins. respectively. Find the magnitude and line of action of the resultant.

The resultant F is given by

$$F = 2 + 4 + 6 + 8 \text{ lbs.}$$
$$\text{i.e., } F = 20 \text{ lbs.}$$

Also

Moment of Resultant about O = Sum of Moments of Components about O.

$$\therefore 20d \text{ (lb. ins.)} = 2 \times 6 \text{ (lb. ins.)} + 4 \times 8 \text{ (lb. ins.)} + 6 \times 12 \text{ (lb. ins.)} + 8 \times 15 \text{ (lb. ins.)}$$

$$\therefore 20d = 12 + 32 + 72 + 120$$
$$\text{i.e., } d = \frac{236}{20}$$
$$= 11{\cdot}8 \text{ ins.}$$

i.e., the line of action of the resultant is 11·8 ins. from O.

Centre of Gravity

Every body consists of an infinite number of small particles, each of which is pulled towards the earth with a force equal to its weight. In Fig. 44, w_1, w_2, w_3, etc., are the weights of the particles and these weights constitute a system of parallel forces. The magnitude and line of action of the resultant of these parallel forces can be determined by the method already indicated. The resultant is the total weight of the body and its line of action passes through a point G which is known as the centre of gravity of the body.

If a trap door is suspended by a hinge, its centre of gravity must lie vertically below the hinge, i.e., the door hangs in a vertical plane. If not, suppose the door hangs as in Fig. 45, with the centre of gravity G at a distance d from the vertical line through the hinge A. Taking

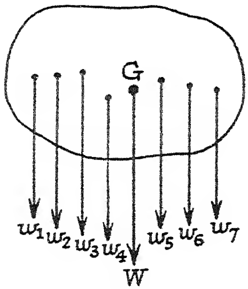


Fig. 44.
CENTRE OF GRAVITY.

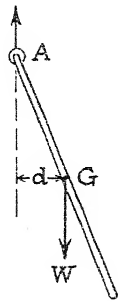


Fig. 45.
CENTRE OF GRAVITY OF A TRAP DOOR.

moments about A there is a resultant clockwise moment Wd, which has no balancing moment. Hence the door ultimately takes up a position with the centre of gravity G vertically below A. In this case the upward reaction at the hinge A is equal and opposite to the weight of the door.

Centres of Gravity of Laminæ and Regular Solids

The centre of gravity of a uniform rod lies at its middle point, since the rod can be balanced on a support at this point. Then the reaction of the support is equal and opposite to the weight of the rod. A thin sheet of material of uniform thickness, in the form of a square, has its centre of gravity at the point of intersection of its diagonals while a thin circular sheet of uniform thickness has its centre of gravity at its centre.

In the case of a cylinder or a rectangular prism the centre of gravity

lies on the line joining the centres of gravity (i.e., centroids) of two opposite faces and midway between them.

STABILITY—A BODY RESTING ON AN INCLINED PLANE

Fig. 46(*a*) shows a wooden block with its base resting on an inclined plane, the force of friction preventing it from slipping. It is common knowledge that, as the inclination of the plane is gradually increased, the block ultimately topples over about the edge AE. When the vertical line through the centre of gravity G lies within the base ABFE (Fig. 46(*a*)), the block is in equilibrium. The weight W of the block exerts a clockwise moment about the edge AE and the reaction R of the plane exerts an equal and opposite moment. If the inclination of the plane is such that the vertical line through G passes outside the base ABFE, i.e., to the left of AE, the block topples over. This is because the weight

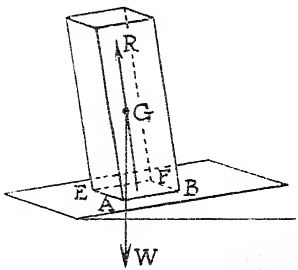


FIG. 46(*a*).

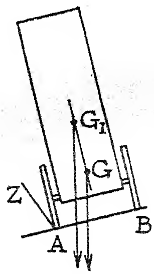


FIG. 46(*b*).

STABILITY OF A BODY RESTING ON AN INCLINED PLANE.

of the block exerts a counter-clockwise moment about the edge AE and there is no balancing clockwise moment.

Let us consider the case of a vehicle such as an omnibus running along the camber of a road (Fig. 46(*b*)). The weight of the engines, etc., near the base causes the vertical line through the centre of gravity G to be well inside the edge AZ. If the centre of gravity were at G_1, the vertical line through G_1 would be much nearer AZ. In the former case a slight displacement of G to the left due to an obstruction would not throw the vertical line through G to the left of AZ and the vehicle would remain upright. In the latter case, however, a slight displacement of G_1 to the left would throw the vertical line through this point to the left of AZ and the vehicle would overturn.

EQUILIBRIUM—STABLE, UNSTABLE AND NEUTRAL

Fig. 47(*a*) shows a circular plate of metal, pivoted at O, with its centre of gravity G vertically below O. The upward reaction R at O is equal and opposite to the weight W. If the plate be displaced to one side its weight, acting through the new position G_1 of the centre of gravity, exerts a moment about the pivot O and, since there is no balancing moment, the plate ultimately resumes its position of rest with the centre of gravity vertically below O. The plate is now in stable equilibrium.

If the plate is in the position shown in Fig. 47(*b*), with G vertically above the pivot O, the plate is still in equilibrium, since the upward reaction R is equal and opposite to the weight W. If, however, there is a slight displacement to one side the weight W, acting through the displaced centre of gravity G_1, exerts a moment about O and the plate rotates until its centre of gravity again resumes a position vertically below O. When the centre of gravity is vertically above O, the plate is in unstable equilibrium.

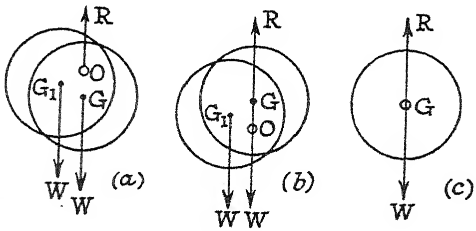


FIG. 47.

EQUILIBRIUM—(*a*) STABLE, (*b*) UNSTABLE, AND (*c*) NEUTRAL.

It will be readily seen from Fig. 47(*a*) that a slight displacement raises the centre of gravity whereas in Fig. 47(*b*) a slight displacement lowers the centre of gravity. Thus for any displacement of a body from its equilibrium position, when the centre of gravity is raised, the body is in stable equilibrium, but if the centre of gravity is lowered the body is in unstable equilibrium.

In Fig. 47(*c*) the plate is pivoted at the centre of gravity G and rests in any position. In this case the plate is in neutral equilibrium.

Exercises III

1. In using a brace and bit, a man exerts a force of 7 lbs. wt. at right angles to the crank. If the radius of the sweep is $4\frac{1}{2}''$, find the turning moment applied.

2. In using a claw hammer for withdrawing a nail, the resistance to extraction is 500 lbs. wt. If the distance of the nail from the fulcrum

is $\frac{5}{8}''$, what effort, applied at right angles to the handle and at a distance of $10\frac{1}{2}''$ from the fulcrum, will extract the nail? (See Fig. 34.)

3. Explain, giving suitable sketches, the mechanical principles applied during the use of a spanner with screw adjustment.

How could each of these principles be illustrated by means of simple experiments?

(C. G. L. I.; Hand. S.) (N.B. See also Chapter VI.)

4. A spanner, 30″ long, is used for screwing a nut on a bolt. A force of 10 lbs. wt. is applied at distances of 5, 10, 15, 20 and 25 inches from the centre of the bolt. Determine the turning moment in each case. Plot a graph, moment against distance from centre of bolt.

5. In cutting a screw thread on a cylindrical rod by means of a stock and die, equal forces of 15 lbs. wt. are applied at right angles to the stock, at a distance of $7\frac{1}{2}$ inches from the centre. Calculate the moment of the couple applied.

6. Explain how the relationship between applied force and weight is calculated in using a simple lever.

(*a*) A weight of 24 lbs. is attached to the end of a uniform rigid steel rod 12 ft. in length and weighing 6 lbs. At what point must the rod be balanced in order that the weight may be raised by applying a force equal to the weight of 8 lbs. to the other end?

(*b*) If one end of the same rod rests on the ground and a force equal to the weight of 8 lbs. acts vertically upwards at the other end, find where the weight of 24 lbs. must be placed in order that the latter may be raised.

(C. G. L. I.; Hand. S.)

7. Explain the meaning of the terms "moment of a force" and "moment of a couple."

A uniform plank weighing 45 lbs. is supported in a horizontal position on two trestles, 12 ft. apart, at its ends. If a man weighing 150 lbs. stands on the plank at a distance of 3 ft. from one of the trestles, find the pressure on each trestle.

(C. G. L. I.; Hand. S.)

CHAPTER IV

FRICTION AND WORK

FRICTION

When two bodies are pressed together, resistance has to be overcome before they can be made to slide on each other. This resistance is known as the force of friction.

If a body A rests on a table (Fig. 48) and a gradually increasing horizontal force F be applied, a frictional resistance F_1 acts in the opposite direction between the body and the table. As F increases so F_1 increases; in fact, so long as the body remains at rest, $F = F_1$. Ultimately F becomes large enough to cause the body to move. The value of the frictional resistance in this case is called the limiting frictional force. This force has to be overcome before the body A can move from rest.

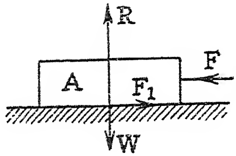


FIG. 48.
FORCE OF FRICTION BETWEEN TWO SURFACES.

EXPERIMENT VIII

To find the relation between the frictional force and the load

The apparatus used in this experiment is shown in plan and elevation in Fig. 49(*a*). AB is a wooden board, of approximate dimensions 2 feet by 3 inches by 1 inch, and C is a slider, also made of wood, of approximate dimensions 4 inches by $2\frac{1}{2}$ inches by 1 inch. A slot, 3 inches long and 1 inch wide, is cut in the end B of the board. Two pieces of steel piping, each $\frac{3}{16}$ inch in internal diameter, serve as bearings for a brass pulley P, 2 inches in diameter and mounted on a spindle, $\frac{1}{8}$ inch in diameter. One end of a piece of string is fastened to a hook in the slider. The string passes over the pulley P, and the other end is attached to a set of slotted weights, divided into tenths and hundredths of a lb. If the bearings are well oiled, the tension in the string is approximately the same throughout its length. In this case, the horizontal force on the slider and therefore the frictional force is approximately equal to the suspended weight.

Determine the weight on the string, which is required to start the motion of the slider. Add $\frac{1}{2}$ lb. to the slider and again find the weight

required to start it. Repeat the experiment with various loads on the slider. Tabulate the results and plot a graph, connecting the frictional force (i.e., the suspended weight) and the load. (Fig. 49(*b*).)

It will be noticed that the slider gains speed as it moves along the board. Now try the effect of helping the slider to start. This can be done by gently tapping the board AB, while gradually increasing the suspended weight. In this case, the slider moves along the board with a

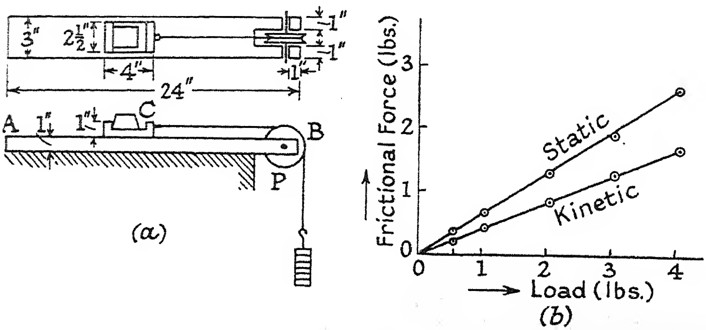


FIG. 49.
FRICTION BOARD AND SLIDER.

fairly uniform speed. Find the suspended weight required to move various loads and again tabulate the results. Plot a graph, showing the relation between the frictional force (i.e., the suspended weight) and the load. (Fig. 49(*b*).)

Load (including slider) W lbs. wt.	Frictional force (slider moved from rest) F_1 lbs. wt.	Frictional force (slider given a start) F_2 lbs. wt.	$\frac{F_1}{W}$	$\frac{F_2}{W}$
0·6	0·39	0·27	0·65	0·45
1·1	0·74	0·50	·67	·45
2·1	1·41	0·88	·67	·42
3·1	1·95	1·29	·63	·42
4·1	2·61	1·75	·64	·43

THE COEFFICIENT OF FRICTION

The table (or the graph) shows that the value of $\frac{F_1}{W}$ for various loads

is approximately constant. Also the value of $\frac{F_2}{W}$ is approximately constant, but this ratio is less than the ratio $\frac{F_1}{W}$.

Static Friction

Is the friction which prevents one body from sliding on another when the two bodies are at rest.

Kinetic Friction

Is the friction which tends to prevent one body from sliding on another, while the bodies are in relative motion.

Thus we have:—

$$\frac{F_1}{W} = \frac{\text{Static frictional force}}{\text{Load}} = \text{a constant (the static coefficient of friction).}$$

and $$\frac{F_2}{W} = \frac{\text{Kinetic frictional force}}{\text{Load}} = \text{a constant (the kinetic coefficient of friction).}$$

The above relationship, whether for static or kinetic friction, is a special case of a more general law which states:—*The frictional force between two surfaces in contact is proportional to the perpendicular force between them* (Fig. 50). The law may be expressed as follows:—

$$\mu = \frac{F}{R}, \text{ where}$$

F = the frictional force,

R = the perpendicular force,

μ = the coefficient of friction.

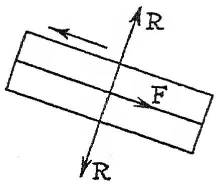


FIG. 50.

FRICTIONAL FORCE AND PERPENDICULAR FORCE.

Laws of Friction for dry surfaces

(1) The direction and magnitude of the frictional force is such as just to preserve equilibrium, provided the limiting frictional force is not exceeded.

(2) The limiting frictional force between two surfaces in contact is proportional to the perpendicular force between the two surfaces.

(3) The frictional force between two surfaces is very nearly independent of the area of the surfaces.

Conditions affecting friction

The value of the coefficient of friction between two surfaces depends on the nature and properties of the materials, viz., (*a*) hardness, (*b*) ability to take on a smooth polish, (*c*) cleanliness of the surfaces and (*d*) lubrication.

With clean dry surfaces, the force of friction is produced by the projections of one surface interlocking with the projections of the other. Even in the case of the surfaces used in machines, although these surfaces appear to be smooth they show certain roughnesses when examined by a microscope. Thus in the movement of one surface over the other, the projections of one surface move over the projections of the other and, when the perpendicular force is large enough, the projections of the softer material are worn away. In machines, the surface which can be easily replaced is made of the softer material, so that the wear is confined mainly to this surface.

Lubrication

If a cast-iron plate with a clean smooth surface is placed on a similar plate, the upper plate moves easily on the lower one. But if pressure is applied at right angles to the surfaces and the upper plate is moved about, the surfaces will adhere together. This is due partly to the removal of the air film between the surfaces, and also to the forces of attraction between the molecules of one surface and the molecules of the other. The effect is also more pronounced when the surfaces are made of the same material.

In practice a film of lubricating oil is placed between the surfaces to keep them apart and the working load (i.e., the perpendicular force) has such a value that the squeezing out of this film is avoided. Thus the two surfaces move relatively to each other with very little applied effort.

The type of oil applied is also very important, because one kind of oil is better suited for a particular purpose than another kind. Generally, thick oils are used when the perpendicular force between the surfaces is great, and thin oils when the perpendicular force is small. Another important point is to apply the oil in the most suitable place. A few methods of applying oil are given below.

Hand Oiling

In this method of oiling the oil is applied at intervals, and the parts to which it is applied are alternately flooded and dry. This method of lubrication is intermittent.

Pad Lubrication

A pad saturated with oil is placed between the surfaces at a point where the greatest pressure exists. The oil rises continuously, through the pores of the pad, to the surfaces.

The Syphon Wick Lubricator

A wick with numerous strands is immersed in a small tank containing the oil, and passes through a hole in the base of the tank. The oil runs down the strands to the surface which requires lubricating.

The Needle Lubricator

Fig. 51 shows a needle lubricator which is often used on shaft bearings, in order to supply oil continuously. The needle AB fits loosely in a plug which is inserted in the base of a small cistern. The oil runs down the narrow space between the needle and the plug to the surface to be lubricated.

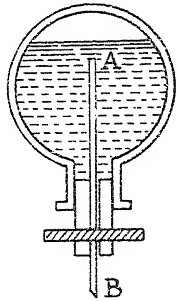


Fig. 51.
NEEDLE LUBRICATOR.

Work

Work is done when the point of application of a force moves.

When a mass of 1 lb. is raised through a vertical distance of 1 foot we have a force of 1 lb. wt. acting vertically upwards, and the point of application of this force moves through a vertical distance of 1 foot. We call the work done in this case the foot pound. Thus the work done by a force of 1 lb. wt., in moving its point of application through a distance of 1 foot in the direction of the force, is the foot pound (ft. lb.). The work done by a force of 3 lbs. wt., in moving its point of application through a distance of 2 feet in the direction of the force, is 6 ft. lbs.

Therefore the work done may be defined as:—

Force applied $\times$ Distance moved by the point of application in the direction of the force. It is very important to understand clearly that it is the distance moved in the direction of the force that is taken. The following example compared with the one above serves to illustrate this point.

Example. Find the work done in moving a block of wood, weighing 1 lb., through a distance of 1 foot along a horizontal table. Coefficient of friction between the two surfaces in contact $= 0{\cdot}2$.

From $\mu = \frac{F}{W}$, where

$$F = \text{frictional resistance to motion,}$$
$$W = \text{weight of block,}$$
$$\mu = \text{coefficient of friction,}$$

we have: $0{\cdot}2 = \frac{F \text{ (lb. wt.)}}{1 \text{ (lb. wt.)}}$

$\therefore F = 0{\cdot}2$ lb. wt.

Hence the work done against this frictional resistance $= 0{\cdot}2 \times 1 = 0{\cdot}2$ ft. lb.

In this example, a horizontal force of 0·2 lb. wt. acts on the block so as to produce motion. The distance moved is one foot, in a horizontal direction.

Power

Power is the rate of doing work. If a weight of 20 lbs. is raised through a vertical distance of 3 feet in one second, the rate of doing work is 60 ft. lbs. per second. But if the time taken is 3 seconds, the rate of doing work is 20 ft. lbs. per second.

The unit of power is the Horse Power, which is equal to a rate of working of 550 ft. lbs. per second.

Example. In planing a board 3 feet long and 6 inches wide, an average forward horizontal force of 35 lbs. wt. is required. If the plane iron cuts a width of $1\frac{1}{2}$ inches per stroke, calculate the work done in planing a shaving off the whole surface.

Number of strokes of 3 ft. long $= \frac{6}{1\frac{1}{2}} = 4.$

Work done per stroke $= 35 \times 3 = 105$ ft. lbs.

$\therefore$ Total work done $= 105 \times 4 = 420$ ft. lbs.

The British Thermal Unit (B. Th. U.)

Heat units will be dealt with in a general manner in Chapter XI. It is sufficient, at present, to define the British Thermal Unit as the quantity of heat which must be imparted to one pound of water to raise its temperature by one degree Fahrenheit.

The Mechanical Equivalent of Heat

On rubbing two rough surfaces together, work is done against friction and heat appears. There is a definite relationship between the work done and the heat which appears, viz.: When 778 ft. lbs. of work are expended, 1 B. Th. U. of heat appears and when 1 B. Th. U. of heat disappears, 778 ft. lbs. of work appear. (See Chapter XII.)

Thus 1 B. Th. U. = 778 ft. lbs.

Friction: Where it is necessary and where it is a disadvantage

In many practical problems, frictional forces have to be reduced in order to reduce the effort required to move one surface over another. The work done and consequently the heat produced is thereby reduced. In machines such as motors and dynamos, the shafts and their bearings tend to become excessively hot and lubrication by suitable oils and in suitable places is necessary. In this way the frictional force is reduced, with a consequent reduction of the heating effect.

It might be imagined that the presence of friction is always disadvantageous. This is not the case, however, because there are many examples, both in everyday life and in workshop appliances, where friction plays an important part and is in fact essential. For instance the presence of friction is necessary to prevent stationary objects from being disturbed by the slightest effort. Friction is also necessary in the case of vehicle wheels, or slipping would take place between the wheel and the ground. In wedge appliances, such as nails, it is the presence of friction which prevents the nail from being withdrawn too easily, thereby increasing the holding power. The wooden handles of tools are held to the tang by the force of friction, as in the case of the various chisels used in wood working. Also the force of friction between the wedge and the blade in some types of plane keeps the blade in position.

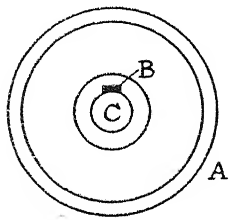


Fig. 52.
SADDLE KEY OF A FLYWHEEL.

In some appliances, for instance the flywheel, the frictional force between the wheel and the shaft is not sufficient to prevent slipping as the wheel revolves and an additional device is necessary to aid the force of friction. This device is the saddle key shown in Fig. 52, where A is the flywheel, fixed to the shaft C and B is the key way into which the saddle key is driven.

Exercises IV

1. Give three examples likely to occur in the workshop where friction is objectionable and indicate what steps are taken to reduce it. Give also three examples where it is necessary and show in each case how it is applied and what purpose it serves.

What general rule directs the choice of the lubricant used in a machine?

(C. G. L. I.; Hand. S.)

2. Find the horizontal force required to move a plane (assuming the blade to be removed), weighing $2\frac{1}{2}$ lbs. along a horizontal board, if the man using it exerts a vertical force of 30 lbs. Coefficient of friction $= 0{\cdot}26$.

3. A smooth weight of 50 lbs. rests on a flat polished surface and is attached by a light horizontal cord passing over a smooth pulley to a smaller weight which hangs freely. If the 50 lb. weight just begins to slip when the smaller weight is 12 lbs., what is the coefficient of friction?

(C. G. L. I.; Hand. S., part question.)

4. In an experiment on the determination of the coefficient of friction between a wooden slider and a horizontal board, the following results were obtained:—

Load + slider lbs. wt. .. W..	1·1	1·6	2·1	2·6	3·1	3·6
Effort (kinetic) lbs. wt. .. F_2..	·50	·70	·88	1·09	1·31	1·55
Effort (static) lbs. wt. .. F_1..	·72	1·01	1·30	1·60	1·95	2·23

Plot graphs connecting Load and Effort in each case and determine the mean coefficients of friction.

5. State the exact scientific meaning of work, power and horse power.

A pump is capable of raising 6,000 gallons of water to a height of 75 feet in 10 minutes. What is the horse power? (1 gallon of water weighs 10 lbs.)

(C. G. L. I.; Hand. S.)

CHAPTER V

THE CONSERVATION OF ENERGY

Velocity and Acceleration for Rectilinear Motion

Velocity

The velocity of a body is the distance traversed by the body in unit time, e.g., 10 feet per second.

A velocity is uniform when the distance traversed in each second is the same. Thus if v is the uniform velocity, s the distance traversed in time t, we have:—

$$\text{Distance traversed in unit time} = v.$$
$$\therefore \text{distance traversed in time } t = vt.$$
$$\therefore s = vt.$$

Acceleration

Acceleration is the rate of increase of velocity and the acceleration is uniform when the rate of increase of velocity is constant. If a train, starting from rest, acquires a velocity of 5 feet per second at the end of the first second, 10 feet per second at the end of the second second, 15 feet per second at the end of the third second and so on, the velocity increases at the rate of 5 feet per second in each second. Thus the acceleration is 5 feet per second per second.

If a body is let fall from a height and is allowed to fall under gravity, the initial velocity is zero, the velocity at the end of the first second is 32 feet per second, and the velocity at the end of the second second is 64 feet per second and so on. Thus the acceleration due to gravity is 32 feet per second per second.

If v is the velocity acquired after t seconds and g the acceleration due to gravity, then:—

$$v = gt \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

Since the initial velocity is zero and the velocity after t seconds is v feet per second, the average velocity during this period is $\frac{1}{2}v$ feet per second, the acceleration being uniform. Hence if s is the distance described, we have:—

$$\text{Distance} = \text{Average velocity} \times \text{Time.}$$

$$\text{i.e., } s = \tfrac{1}{2} vt \quad .. \quad (2)$$

$$\text{Now from (1) } t = \frac{v}{g}$$

$$\text{and from (2) } t = \frac{2s}{v}$$

$$\therefore \frac{v}{g} = \frac{2s}{v}$$

$$\text{and } v^2 = 2gs \quad .. \quad (3)$$

Multiply both sides of this equation by $\frac{1}{2}$ m, where m is the mass of the falling body in lbs.

$$\text{Hence } \tfrac{1}{2} mv^2 = mgs$$

$$\text{and } \frac{mv^2}{2g} = ms \quad .. \quad (4)$$

Kinetic Energy

The work expended by a force of 1 lb. wt. in moving its point of application through 1 foot = 1 ft. lb. Hence the work expended by the weight of m lbs. which falls through s feet = ms ft. lbs.

$$= \frac{mv^2}{2g} \text{ ft. lbs. (from (4)),}$$

where v is the velocity acquired from rest, under the acceleration of gravity.

The quantity $\frac{mv^2}{2g}$ is the kinetic energy acquired by the body.

Thus: Work expended = Kinetic energy gained.

Potential Energy

Potential energy is the energy of a body due to its position and is its capacity for doing work. If a body is let fall, its potential energy decreases, but it acquires kinetic energy, i.e., energy of motion. Thus potential energy and capacity for doing work are two different ways of expressing the same idea. We may summarise as follows:

Potential energy lost = Kinetic energy gained.
or Work expended = Kinetic energy gained.

The Conservation of Energy

When work or potential energy is expended an equivalent amount of kinetic energy appears. In the case of a body resting on a table, the body possesses potential energy or energy due to position. If the table is pulled from underneath the body, the body falls under gravity and acquires kinetic energy or energy of motion. The potential energy is thus transformed into kinetic energy.

This transformation of potential into kinetic energy is well illustrated in the case of a water wheel. Fig. 53 shows a model of a water wheel of the over-shot type, which has buckets fixed at regular intervals along its circumference. As the water falls from the high to the low level, some of the potential energy of the water is converted into kinetic energy and this is transmitted to the wheel, causing it to rotate. The kinetic energy of the wheel is then transmitted to the machinery geared to it.

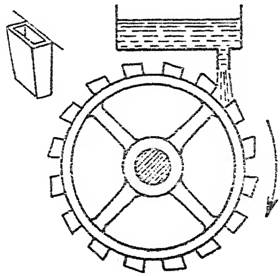


Fig. 53.
OVERSHOT WATER WHEEL.

Just as work may be converted into an equivalent amount of kinetic energy, so when kinetic energy is destroyed, an equivalent amount of work appears.

Let us consider the case of driving a nail into a block of wood. The head of the hammer is brought to rest and the kinetic energy destroyed is converted into work. This work causes the nail to enter the wood, against the resisting force.

The Principle of the Conservation of Energy

Energy can neither be created nor destroyed, but it can be transformed from one kind into another.

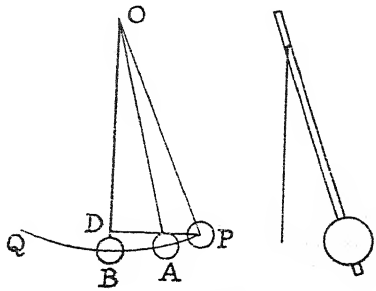
If a certain amount of energy is imparted to a machine by the application of a force or effort through a distance, work is done against the load or resistance. In an actual machine, the useful work is always less than the energy supplied to the machine. Some of the energy is required to overcome the friction. This energy is transformed into heat energy, energy of sound, etc. In machines, the energy used to overcome friction and the energy which produces sound are examples of wasted energy and should be reduced as far as possible.

As an example of the waste of energy, let us consider the steam engine. Coal is burned in the boiler furnace and only a fraction of the heat

produced is used for raising the temperature of the water in the boiler and converting it into steam. A large amount of heat is lost in raising the temperature of the boiler, some is carried away by the flue gases and some is lost to the air near the furnace. Thus as far as the heat produced by the combustion of the coal is concerned, only a small fraction is used to produce steam.

The Simple Pendulum

The simple pendulum is an example of the conversion of potential into kinetic energy. Theoretically the pendulum consists of a small metallic sphere A which is suspended from a rigid support O by means of a thin thread. The metallic sphere, known as the pendulum bob, swings to and fro along the arc PBQ of the circle whose centre is the point of suspension O (Fig. 54(*a*)). When the bob is passing through the lowest point B of the arc, its potential energy may be considered zero. If the velocity of the bob as it passes through B is v feet per second, this velocity is a maximum. Hence the kinetic energy at this point, viz., $\frac{mv^2}{2g}$ ft. lbs., where m is the mass in lbs., is also a maximum. When, however, the bob is in either of its extreme positions P or Q, it is momentarily at rest, its kinetic energy is zero and its potential energy is ms, i.e., m. BD ft. lbs., where D is the foot of the perpendicular drawn from P to the vertical line OB. Thus as the bob falls from P to B, all its potential energy is converted into kinetic energy.



(*a*) (*b*)

FIG. 54.
SIMPLE PENDULUM.

As the pendulum bob continues to move to and fro, the arc PQ gradually decreases until the bob takes up a position of rest at B. The energy of vibration is dissipated by the work done against the friction of the air.

A complete oscillation is the path BPBQB and the period of oscillation T is the time required for the bob to describe this path.

Suppose a small metal ball ($\frac{1}{2}$ inch diameter) is supported by means of a thread about 60 inches long, from the clamp of an iron stand which rests on the bench. Suppose the time of 20 complete oscillations is

noted by means of a stop watch reading to $\frac{1}{5}$ second, and the length of the pendulum from the point of support to the centre of the bob is measured. If the length of the string is decreased and the time of 20 oscillations is again noted and so on, the period of oscillation T for each length l of the pendulum can be determined. A typical set of results is shown in the following table.

Length of pendulum l (inches)	Time of 20 oscillations (seconds)	Period T seconds	$\sqrt{l}$	$\frac{T}{\sqrt{l}}$
60·0	49·8	2·49	7·74	0·322
45·5	43·4	2·17	6·74	0·322
40·1	40·6	2·03	6·33	0·321
29·5	35·4	1·77	5·43	0·326
20·3	29·0	1·45	4·50	0·322
15·8	25·4	1·27	3·97	0·320

The value of $\frac{T}{\sqrt{l}}$ as shown in the last column is a constant, viz., 0·323. This shows that the period T is proportional to the square root of the length.

Hence $T = \cdot 32\sqrt{l}$, where l and T are measured in inches and seconds respectively.

The theoretical relation between the period of oscillation and the length is given by

$T = 2\pi\sqrt{\frac{l}{g}}$, where g is the acceleration of gravity. When l is measured in inches, g is equal to 32 feet per second per second or 384 inches per second per second.

$$\therefore T = \frac{2 \times 3\cdot 142\sqrt{l}}{\sqrt{384}}$$

$$\text{i.e., } T = 0\cdot 32\sqrt{l}$$

This is a result which is in close agreement with the formula established experimentally.

Pendulums are used in practice for controlling the speed of mechanisms. One of these is the pendulum clock in which the pendulum consists of a large brass disc at the end of a thin metallic rod (Fig. 54(*b*)).

Each time the pendulum passes through its mean position it receives an impulse at a point near its support. This impulse is given to it by a system of levers, controlled by the mechanism of the clock. Thus the pendulum is maintained in vibration and, since its period is constant, it controls the speed of the clockwork.

Newton's Law of Motion and Centrifugal Force

It is common experience that a body at rest remains at rest unless acted upon by a force and that a moving body continues to move in a straight line unless acted upon by some force which either brings it to rest or changes its direction of motion. The body is said to possess Inertia. Thus an express train, when steam is shut off, is brought to rest by the force of friction between the brake shoes and the wheels. If the brakes are not applied, the train would eventually come to rest owing to the resistance of the air, the frictional force between the wheels and the rails, etc.

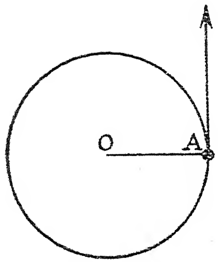


Fig. 55.
CENTRIFUGAL FORCE.

To understand how a moving body continues to move in a straight line unless acted upon by a force, consider a solid body A, tied to a string and whirled in a circle with the hand at the centre O (Fig. 55). The force which prevents the body from describing a straight line acts from A to O and, if this force is removed, i.e., if the string breaks, the body flies off at a tangent.

Sir I. Newton crystallised the above ideas in his law of motion which states that every body continues in a state of rest or of uniform velocity in a straight line, unless acted upon by some impressed force.

As we have seen, the force which keeps the body A (Fig. 55) in the circular path acts along AO and, since action and reaction are equal and opposite, a force acts from O to A. This force, known as the centrifugal force, tends to increase the length of the string and when the force is large enough the string breaks.

The Flywheel

The action of the flywheel of a steam engine is an example of centrifugal force. When the wheel is revolving, the spokes are in considerable tension. As the number of revolutions per second increases, the tension in the spokes increases. If the speed of the wheel is increased

beyond a certain limit, the maximum force which the spokes can withstand is exceeded. The flywheel "bursts" and portions of the rim, in which nearly all the mass is concentrated, fly off at a tangent.

The flywheel when in motion possesses kinetic energy which is equal to $\frac{mv^2}{2g}$ ft. lbs., where v is the speed of a point on the rim in feet per second, m is the mass of the wheel (supposed to be concentrated at the rim) in lbs. and g, the acceleration of gravity, viz., 32 ft. per second per second.

Example. A flywheel, of diameter 4 feet, is revolving at the rate of 600 revolutions per minute. If the mass, supposed to be concentrated at the rim, is 500 lbs., calculate the kinetic energy of the wheel.

$$\text{Speed of a point on the rim} = \pi \times 4 \times \frac{600}{60}$$
$$= 40\pi \text{ ft. per second.}$$

Hence the kinetic energy of the flywheel

$$= \tfrac{1}{2} \times 500 \times (40\pi)^2 \times \tfrac{1}{32} \text{ ft. lbs.}$$
$$= 125{,}000 \text{ ft. lbs.}$$

From the preceding problem it can be seen that the revolving flywheel possesses a considerable amount of kinetic energy. Since the mass is constant, the kinetic energy varies as the square of the speed, and any change of speed produces a corresponding change in the kinetic energy.

The Governor of a Steam Engine

The principle of centrifugal action is utilised in the governor of a steam engine. The essential features of the governor, together with the throttle valve which works in conjunction with it, are shown in Fig. 56. A pulley A is rotated by means of a belt from the crank shaft and the motion is transmitted to the spindle B by means of the bevel wheels C and D. (See Chapter VII.) This spindle is pivoted at its lower end and to its upper end

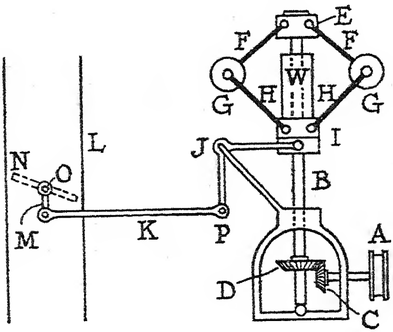


Fig. 56.

GOVERNOR OF A STEAM ENGINE.

a collar E is fixed. Steel rods FF, attached by pins to the collar E, have heavy steel balls GG at their lower ends. These balls are attached by pins to the steel rods HH, whose lower ends are pinned to the sleeve I which moves along the spindle. A bent lever, pivoted at J, has one arm connected to a collar on the sleeve I and the other arm connected to the horizontal rod K. The other end of the rod K is pinned to the lower end of a lever M. This lever controls the throttle valve which consists of a disc N, mounted on the axle O. The position of this disc controls the amount of steam which passes along the pipe into the cylinder of the engine.

When the spindle is rotating slowly, the balls GG describe a circle which, by centrifugal action, increases in diameter. The sleeve I moves up the spindle and the end P of the bent lever moves to the right. The lower end of the lever M also moves to the right and the disc N sets itself more nearly at right angles to the steam pipe. The passage of the steam is practically cut off, the crank shaft and consequently the spindle B rotate at a reduced speed and the balls GG describe a circle of gradually decreasing diameter. The weight W forces the sleeve I down the spindle and the lower end of the lever M moves to the left. In this way, the disc N acquires a position nearly parallel to the pipe and more steam is allowed to pass. Thus, by centrifugal action, the governor automatically controls the supply of steam along the steam pipe and consequently the speed of the crank shaft.

Exercises V

1. Explain, with suitable reference to scientific principles involved, the action of the flywheel of an engine.

(C. G. L. I.; Hand. S.)

2. Briefly indicate the transformations of energy that take place between the burning of fuel under a boiler and the cutting of a screw thread by an electrically driven lathe. Point out where and why important losses of energy take place.

(C. G. L. I.; Hand. S.)

3. Explain the meaning of the term "work" as used in mechanics. In what units can it be expressed?

A load of 2 tons is raised to the surface of a pit, which is 570 ft. deep, by means of a uniform cable, weighing $3\frac{1}{2}$ lbs. per foot. Calculate the work done in raising the load.

(C. G. L. I.; Hand. S.)

4. An emery wheel has a peripheral speed of 1,000 ft. per minute. If the diameter of the wheel is 20 inches, calculate the number of revolutions per second.

5. A flywheel of mass 1,000 lbs., whose rim has a mean radius of 3 ft., runs at 180 R.P.M. If 2,000 ft. lbs. of energy are taken from it, calculate the new speed.

(N.B. The whcle mass of the wheel may be considered to be concentrated in the rim.)

CHAPTER VI

MACHINES (A)

Simple Machines

A piece of mechanism by which a force, applied at one point, is transmitted for use at some other point, in a different form, is known as a machine.

When the resistance is so large that direct action is impossible, this resistance acting through a small distance may be overcome by a small effort acting through a much larger distance. Thus in the case of a lever with unequal arms, if the load is applied at the end of the shorter arm and the effort at the end of the longer arm, the effort moves through a greater distance than the load.

The Wheel and Axle

The wheel and axle, which to some extent is similar to the lever, consists of two cylindrical rollers, fixed to a spindle which is coincident with the axes of the rollers. The larger roller is called the wheel and the smaller one, the axle. The spindle rests on well oiled bearings.

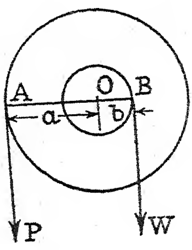


Fig. 57.
WHEEL AND AXLE PRINCIPLE.

Fig. 57 shows a section of the wheel and axle, at right angles to the spindle. A string, one end of which is fastened to a small screw, passes round the axle and supports a load W at the other end. Another string, fastened in a similar manner, passes round the wheel in the opposite direction. To the end of this string, the effort P is applied.

Applying the Principle of Moments about the axis of the spindle, we have:—

$Pa = Wb$, where a and b are the radii of the wheel and axle respectively.

If we multiply both sides of this equation by 2π, we obtain:—

$$P \times 2\pi a = W \times 2\pi b.$$

Hence if the machine makes a complete turn, the effort moves down-

wards through a vertical distance of $2\pi a$, while the load moves upwards through a vertical distance $2\pi b$. Also we have:—

Effort $\times$ Distance Effort moves = Load $\times$ Distance Load moves, i.e., Work done by Effort = Work done against Load.

This result is true, of course, only if friction is absent.

The Principle of Work

The Principle of Work states that *in a machine the work done by the effort is equal to the work done against the load, if friction is absent.*

This principle has been established for a wheel and axle, but it is also true in the case of many other machines.

Mechanical Advantage and Velocity Ratio

The mechanical advantage of a machine is given by:—

$$\text{Mechanical Advantage} = \frac{\text{Load}}{\text{Effort}}$$

Thus if a load of 6 lbs. wt. is raised by an effort of 2 lbs. wt., the mechanical advantage is $\frac{6 \text{ lbs. wt.}}{2 \text{ lbs. wt.}}$ i.e., 3.

The velocity ratio of a machine may be defined as:—

$$\text{Velocity Ratio} = \frac{\text{Distance Effort moves}}{\text{Distance Load moves}}$$

If the effort moves a distance of 6 feet and the load 2 feet, the velocity ratio of the machine is $\frac{6 \text{ ft.}}{2 \text{ ft.}}$ i.e., 3.

The Efficiency of a Machine

No machine is entirely free from friction, although in Chapter IV we saw how friction may be reduced to a large extent by lubrication. Thus we can never obtain as much work out of a machine as we put into it. This means that the work done by the effort is always greater than the work done against the load or resistance.

The efficiency of a machine may be defined thus:—

$$\text{Efficiency} = \frac{\text{Useful work obtained from the machine}}{\text{Work put into the machine}}$$

$$= \frac{\text{Load} \times \text{Distance Load moves}}{\text{Effort} \times \text{Distance Effort moves}}$$

$$= \frac{\text{Load}}{\text{Effort}} \div \frac{\text{Distance Effort moves}}{\text{Distance Load moves}}$$

$$= \frac{\text{Mechanical Advantage}}{\text{Velocity Ratio}}$$

Experiment IX

To determine the efficiency of a wheel and axle for various loads

A model wheel and axle which can be constructed out of wood is shown in front and side elevation in Figs. 58(*a*) and (*b*). The dimensions of the various parts are given in the diagrams. A is the wheel, 8″ in diameter and $\frac{3}{4}$″ thick, and B is the axle, 2″ in diameter and $1\frac{1}{2}$″ long. Both the wheel and the axle are mounted on a steel spindle, $\frac{3}{16}$″ in diameter. Two pieces of steel piping, $\frac{1}{4}$″ in internal diameter, are fixed by clips to the supports C and D and serve as bearings for the spindle.

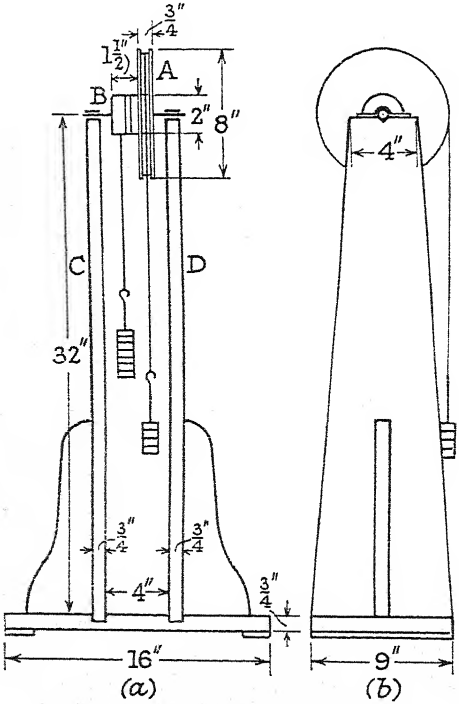


FIG. 58.

WORKING MODEL OF A WHEEL AND AXLE.

A piece of thin string, with one end fastened to a small screw in the circumference of the axle, is wound round the axle a few times, and the other end of the string supports a set of slotted weights (tenths and hundredths of a lb.) which serve as the load.

One end of another string is fixed to a screw in the circumference of the wheel and, after passing round the wheel a few times, supports a

set of slotted weights (tenths and hundredths of a lb.) which serve as the effort.

To perform an experiment, place a small load (e.g., 0·05 lb.) on the load string and suspend weights from the effort string until the load just begins to rise. Repeat the operation for loads 0·1, 0·2, 0·3 lbs., etc., and calculate the mechanical advantage in each case. Measure the diameters of the wheel and the axle and calculate the velocity ratio of the machine. Then calculate the efficiency of the machine for each load, and tabulate the results as below:—

$$\text{Velocity Ratio} = \frac{8''}{2''} = 4.$$

Load (W) lbs.	Effort (P) lbs.	Mech. Adv. W/P	Efficiency
0·05	0·02	2·5	0·63
·10	·03	3·33	·83
·20	·06	3·33	·83
·30	·08	3·75	·94
·50	·13	3·85	·96
·80	·21	3·81	·95
1·00	·26	3·85	·96

Plot a graph showing the relation between the efficiency and the load (Fig. 59).

From the graph it will be seen that the efficiency of the machine gradually increases as the load increases. When the load becomes appreciable, the rate of increase of the efficiency with the load decreases until the curve becomes approximately parallel to the load axis.

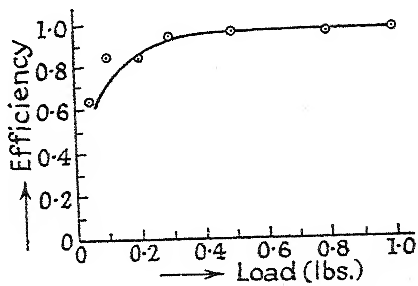


FIG. 59.
EFFICIENCY AND LOAD CURVE.

THE INCLINED PLANE

Suppose ABC (Fig. 60(a)) represents a smooth inclined plane. Let a load of weight W be drawn up the plane by a force P, applied in a direction parallel to the plane. Employing the principle of work, we have:—

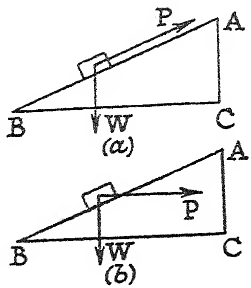


FIG. 60.
INCLINED PLANE.

Work done by Effort = Work done against Load, if friction is absent. i.e., Effort × Distance Effort moves along the plane = Load × Distance Load moves vertically.

$$\text{Hence } P \times AB = W \times AC$$

$$\text{or } \frac{W}{P} = \frac{AB}{AC} = \frac{\text{length of plane}}{\text{height of plane}} = \text{Velocity Ratio.}$$

If the force is applied parallel to the base of the plane, we have:—

$$P \times BC = W \times AC \text{ (Fig. 60(}b\text{))}$$

$$\text{i.e., } \frac{W}{P} = \frac{BC}{AC} = \frac{\text{base of plane}}{\text{height of plane}} = \text{Velocity Ratio.}$$

In an inclined plane, friction is always present to a greater or lesser extent. The efficiency of the plane (Fig. 60(*a*)) is given by:—

$$\text{Efficiency} = \frac{\text{Mechanical Advantage } \left(\frac{W}{P}\right)}{\text{Velocity Ratio } \left(\frac{AB}{AC}\right)},$$

where P is the effort, acting along the plane, required to move the load W and overcome the friction.

The Wedge

The wedge shown in Fig. 61 is made up of two inclined planes, base to base. The wedge is shown splitting a piece of timber. A force is applied on the end AB, just sufficient to overcome the resistance to penetration, which includes the resistance due to friction. Thus if the resistance to penetration is equal to 2P (P on each side of the wedge) the force applied on AB (viz., that due to the impact of a hammer) is equal to 2P. In this case, P corresponds to the effort applied parallel to the base of the inclined plane and R, the resistance of the fibres to separation, corresponds to the load. The points D and E move up the planes as the wedge is driven down and thus we have the identical case of a load being forced up an inclined plane by a force applied parallel to the base.

A good example of the wedge is the action of a chisel. Figs. 62(*a*) and (*b*) show a chisel shaving a surface across the grain and along the grain respectively. In cutting across the grain, the resistance of the fibres to

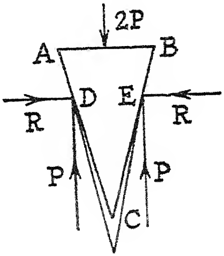


FIG. 61.

PRINCIPLE OF THE WEDGE.

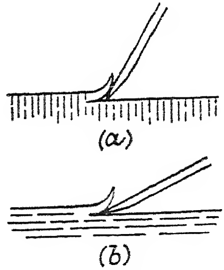


FIG. 62.

ACTION OF A CHISEL.

separation is greater than that in cutting along the grain, and consequently the effort applied to the chisel in the former case is greater than in the latter.

THE SCREW

If a right-angled triangle ABC, cut out of a sheet of paper, is wrapped round the cylinder D, an effect such as that shown in Fig. 63 is obtained. From this figure it can be seen that the screw is really an inclined plane wrapped round a cylinder.

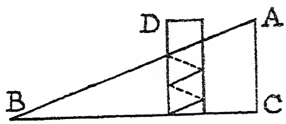


FIG. 63.

PRINCIPLE OF THE SCREW.

THE SCREW JACK

Fig. 64 shows a screw jack which is used for raising heavy objects from the ground. ABC is the tripod (two legs only being shown), threaded at C, so that the square cut screw D turns in it. E is the platform, fixed rigidly to the screw, and FG is the arm or lever. The effort P is applied at right angles to the arm at the end F. For one complete revolution of the arm the load W, placed on the platform, is raised a distance equal to the pitch of the screw, i.e., the distance between any two consecutive threads. Thus the velocity ratio

$$= \frac{\text{Circumference of circle which Effort describes}}{\text{Pitch of Screw.}}$$

In an actual screw-jack friction is present to a smaller or larger extent according to whether the machine is lubricated or unlubricated. If P is the effort and W the load, the Mechanical Advantage $= \frac{W}{P}$

and the Efficiency $= \dfrac{\text{Mechanical Advantage}}{\text{Velocity Ratio}}$

$$= \frac{W}{P} \div \frac{2\pi a}{p}, \text{ where}$$

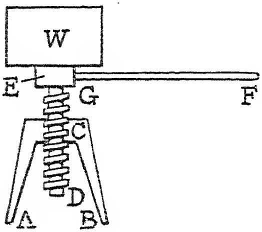


FIG. 64.
SCREW JACK.

a is the length of the lever arm, and p the pitch of the screw.

Example. A load of 4,800 lbs. wt. has to be raised by a screw jack. If the length of the lever is $2\frac{1}{2}$ feet and the pitch of the screw $\frac{3}{8}$ inch, find the effort which must be applied at the end of the lever (*a*) assuming friction to be absent, (*b*) if the efficiency for this load is 40%.

(*a*) Let P = the effort applied (in lbs. wt.). Work done by Effort for one complete revolution

$$= P(\text{lbs. wt.}) \times 2\pi \times 2\tfrac{1}{2}(\text{ft.}).$$

Work done against Load $= 4{,}800(\text{lbs. wt.}) \times \frac{3}{8} \times \frac{1}{12}(\text{ft.}).$

$$\therefore P(\text{lbs. wt.}) \times 2\pi \times 2\tfrac{1}{2}(\text{ft.}) = 4{,}800(\text{lbs. wt.}) \times \tfrac{3}{8} \times \tfrac{1}{12}(\text{ft.}).$$

$$\therefore P = 9{\cdot}55 \text{ lbs. wt.}$$

(*b*) Velocity Ratio $= \dfrac{2\pi \times 2\frac{1}{2}(\text{ft.})}{\frac{3}{8} \times \frac{1}{12}(\text{ft.})} = 502{\cdot}4.$

Efficiency $= \dfrac{\text{Mechanical Advantage}}{\text{Velocity Ratio}}$

$$\therefore 0{\cdot}4 = \frac{\text{Mech. Adv.}}{502{\cdot}4}$$

$$\therefore \text{Mech. Adv.} = 0{\cdot}4 \times 502{\cdot}4 = 201{\cdot}0$$

Hence: $\dfrac{\text{Load}}{\text{Effort}} = 201{\cdot}0$

i.e., $\dfrac{4{,}800(\text{lbs. wt.})}{P(\text{lbs. wt.})} = 201{\cdot}0$

$$\therefore P = 23{\cdot}9 \text{ lbs. wt.}$$

The Brace and Bit

The mechanical principles involved in the action of a brace and bit are (*a*) the wedge or chisel principle and (*b*) the wheel and axle principle. Fig. 65 represents a brace and bit, where A is the head, the circular wooden portion being the head handle. BCDE is the crank, to which is attached a loose fitting handle F, known as the crank handle. G is a two-jawed chuck, into which the bit H is fitted. (N.B. the bit shown in the diagram is the spur of a centre bit with the centre removed.) A rigid fit is obtained by means of the chuck shell which is screw-threaded on its inside.

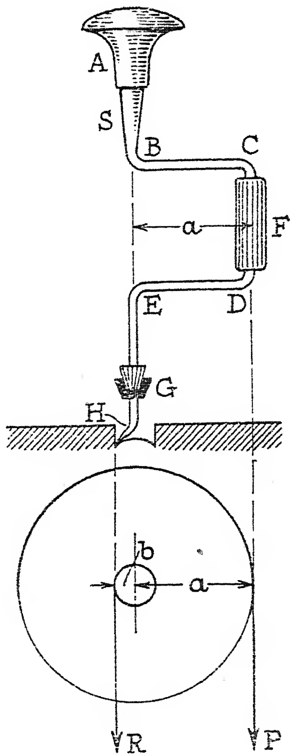


Fig. 65.
BRACE AND BIT.

The wedge action will be considered first. The downward force on the head handle causes the edge of the bit to penetrate the fibres. This penetration has to be effected along the surface of the cylinder (i.e., the hole to be bored) and the wheel and axle principle now operates. The effort P, applied to the crank handle, describes the circle (known as the sweep) of radius *a*, and the cutting edge describes the circle whose radius is b.

As far as the wheel and axle principle is concerned, we may leave out of account the effort on the head handle and the consequent advance of the cutting edge through the wood. Thus the velocity ratio is $\frac{2\pi a}{2\pi b}$ or $\frac{a}{b}$ and the mechanical advantage R/P, where R is the resistance to the advance of the cutting edge along the circumference of the circle of radius b.

Friction is considerably reduced by the use of ball bearings between the shank SB and the head, and the efficiency is consequently increased.

The Stock and Die

Fig. 66 shows a stock and die which is used for cutting screw threads. AB is the stock and CD the die, consisting of two pieces. The cylin-

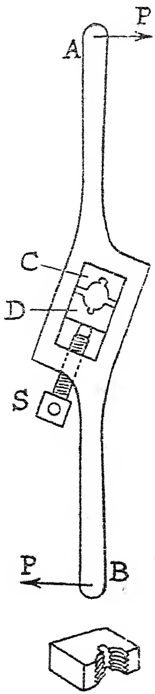


FIG. 66.
STOCK AND DIE.

drical tube or rod, which has to be screw cut, is held rigidly between the cutting edges by means of the screw S. An enlarged view of the die is also shown.

An effort P is applied at each end of the stock at right angles to its length. If R is the resistance to the advance of the die along the cylindrical tube, then the mechanical advantage is equal to $\frac{R}{2P}$

The velocity ratio =

$$\frac{\text{Circumference of circle described by the Effort}}{\text{Pitch of Die Thread}}$$

The Wrench and Tap

The wrench and tap which is used for cutting screw threads on the inside of cylindrical tubes, is based on exactly the same principle as the stock and die.

The Nut and Bolt

Fig. 67 shows the action of a spanner, in screwing a nut on to a bolt, so as to press together two pieces of wood. The nut can be screwed by the hand for a certain distance, but the spanner is required to press the two pieces of wood tightly together.

The mechanical advantage =

$$\frac{\text{Perpendicular force between the pieces of wood}}{\text{Effort applied at the end of the spanner}}$$

and the velocity ratio =

$$\frac{\text{Circumference of circle traced out by the effort P}}{\text{Pitch of Screw}}$$

The Screwdriver and Screw

Fig. 68 shows a screwdriver which is withdrawing a screw from a block of wood. A couple is applied to the handle and its turning moment

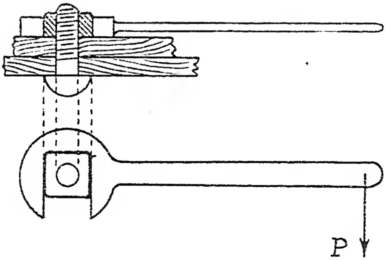


FIG. 67.

NUT AND BOLT.

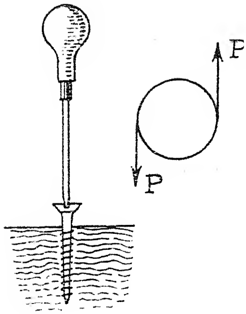


FIG. 68.

SCREW AND SCREW DRIVER.

has the effect of causing the screw to leave the wood. The action is similar to that of a simple screw jack and the velocity ratio =

$$\frac{\text{Circumference of circle traced out by Effort P}}{\text{Pitch of Screw}}$$

Exercises VI

1. State and discuss briefly the mechanical principles involved when:—
   (*a*) a nail is being driven by a hammer into a piece of wood,
   (*b*) a screwdriver is being used to insert a screw.

(C. G. L. I.; Hand. S.)

2. Describe one tool or workshop appliance in which the principle of levers is applied so that mechanical advantage is obtained. By reference to it make clear the meaning of (*a*) velocity ratio, and (*b*) the principle of the conservation of energy.

(C. G. L. I.; Hand. S.)

3. Explain, with suitable reference to scientific principles involved, the action of two of the following:—
   (*a*) The flywheel of an engine.
   (*b*) The thread of a screw.
   (*c*) A carpenter's brace.

(C. G. L. I.; Hand. S.)

4. In a simple lifting machine it is found that the efforts required to raise various loads are set out below—

Load W lbs.	14	28	42	56	70	84	98	112
Effort E lbs.	3·8	5·2	6·6	8·0	9·4	10·8	12·2	13·6

Draw the load-mechanical advantage graph for the machine and determine the mechanical advantage when the load is 90 lbs.

(*Note.*—The mechanical advantage is given by the ratio $\frac{\text{load}}{\text{effort}}$)

(U. L. C. I.; B.S.)

5. Explain the method which you would use if you wished to calculate the height to which you would raise one end of the flat surface in order that the 50 lb. weight might just begin to slip without the application of any other force than gravity.

(C. G. L. I.; Hand. S.)

(Continuation of Question 3, Exs. IV).

6. Describe a method of finding the efficiency of a screw jack.

A screw jack requires a force of 50 lbs. acting at a radius of 28 ins. to turn it when loaded. If its efficiency is 35 per cent., what is the greatest load it will lift if the pitch of the screw is $\frac{1}{4}$ inch?

(C. G. L. I.; Hand. S.)

7. Is it easier for a man to pull or to push a roller uphill? Give reasons and diagrams to illustrate your answer.

A metal casting weighing 300 lbs. is put into a wheelbarrow. The centre of the metal is 16 in. and the handles of the barrow are 40 in. from the axis of the wheel. What force is required to raise the handles?

(C. G. L. I.; Hand. S.)

8. What is (*a*) a foot-pound, (*b*) one horse power?

A crane worked by a 10-h.p. motor has an efficiency of 75 per cent. What load will it lift through a height of 40 feet in half a minute?

(C. G. L. I.; Hand. S.)

9. A valve is operated by means of a wheel 18 in. in diameter, turning a screw of which the pitch is $\frac{1}{2}$ in. What is the velocity ratio of the mechanism?

(C. G. L. I.; Hand. S.)

CHAPTER VII

MACHINES (B)

PULLEYS

THE SIMPLE PULLEY

A simple method of raising a load is by means of a simple pulley A, shown in front and side elevation (Figs. 69(*a*) and (*b*)). A string which passes over the pulley supports the load W at one end, and at the other end the effort P is applied. If there is no stiffness in the string and no friction between the spindle and its bearings, the tension in the string is the same throughout its length. In this case the load is equal to the effort Also the velocity ratio is unity.

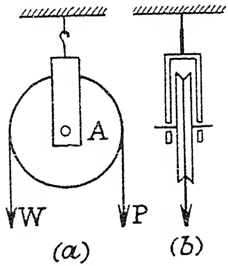


FIG. 69.
SIMPLE PULLEY.

In an actual machine, friction causes the effort to be greater than the load and the efficiency is given by:—

$$\text{Efficiency} = \frac{\text{Mechanical advantage}}{\text{Velocity ratio}}$$
$$= W/P \div 1$$
$$= \frac{W}{P}, \text{ where W is the load and P the effort.}$$

ONE MOVABLE AND ONE FIXED PULLEY

Fig. 70 represents the front and side elevations of a model pulley stand, for which suitable dimensions are given. AB is the overhead beam along which the sliding supports C and D can be moved. One of these supports is shown in front and side elevation (inset). A brass pulley X is attached to the support D by means of a piece of string and serves as the fixed pulley. One end of another piece of string is attached to the support C and, after passing round the pulleys Y and X, the string supports a set of slotted weights which serve as the effort P. A set of slotted weights is suspended from the movable pulley Y and serves as the load W. Suppose the effort P moves down a distance of 1 foot. The two portions of the string supporting the load W are each shortened by ½ ft. and therefore the velocity ratio is 2.

If friction and stiffness of string are absent, the tension of the string is the same throughout its length. Also if the movable pulley has negligible weight we have: $W = 2P$.

In an actual system of pulleys, where friction is present and the weight of the movable pulley cannot be neglected, the efficiency =

$$\frac{\text{Mechanical Advantage}}{\text{Velocity Ratio}} = \frac{W}{P} \div 2 = \frac{W}{2P}$$

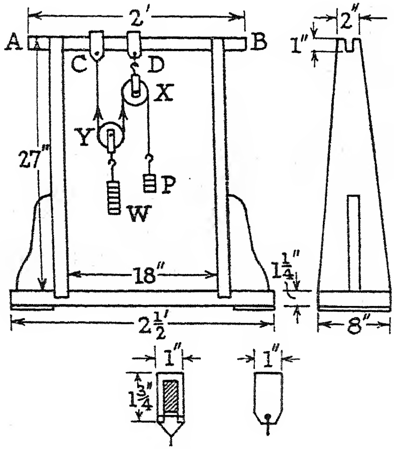


FIG. 70.

WORKING MODEL OF A PULLEY SYSTEM.

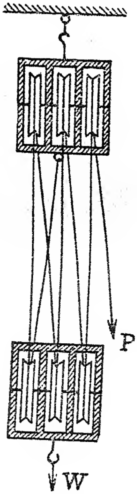


FIG. 71.

BLOCK AND TACKLE.

THE BLOCK AND TACKLE

Fig. 71 shows a block and tackle which consists of two blocks, one fixed to an overhead beam and the other movable. Each block contains three pulleys. A string is attached to a hook in the fixed block and passes round the pulleys as shown. A load W is suspended from the movable block and the effort P is applied to the free end of the string. Suppose the lower block is at a considerable distance below the upper block, so that the strings are approximately vertical.

If the effort P moves downwards through a distance of 6 inches, the six strings which support the lower block are together shortened by 6 inches, each string being consequently shortened by 1 inch. Hence the load W is raised 1 inch and the velocity ratio is 6. If friction and stiffness of the string are absent and the weight of the lower block is

negligible compared with the load, each string supports one-sixth of the load and the mechanical advantage is also 6.

In an actual block and tackle, the lower block has an appreciable weight and this, together with friction, reduces the efficiency of the machine. In this case the efficiency is given by:—

$$\text{Efficiency} = W/P \div 6 = \frac{W}{6P}$$

The Wheel and Differential Axle

Figs. 72(*a*) and (*b*) show the front and side elevations of a model wheel and differential axle which can be used with the wheel and axle stand, shown in Fig. 58. Suitable dimensions are indicated in the diagrams. A and B are two wooden drums and R is the wheel, also made of wood. The drums and the wheel are mounted on a steel spindle 6 inches long and $\frac{3}{16}$ inch in diameter. Two pieces of steel piping, each $\frac{3}{4}$ inch long and $\frac{1}{4}$ inch in internal diameter, are fixed to the supports by clips (Fig. 72(*b*)) and serve as bearings for the spindle. One end of a piece of string is attached to a small screw in the circumference of the drum A and a few turns are wrapped round this drum. The string then passes downwards through a brass pulley Q, $2\frac{3}{4}$ inches in diameter, and upwards to the drum B, round which it is wound in the opposite direction to the string on the drum A. The end of the string is fastened to a small screw in the circumference of the drum B. Another string is attached to a screw in the circumference of the wheel and passes round the wheel in the opposite direction to the string on the drum B. The effort is applied at the end of this string.

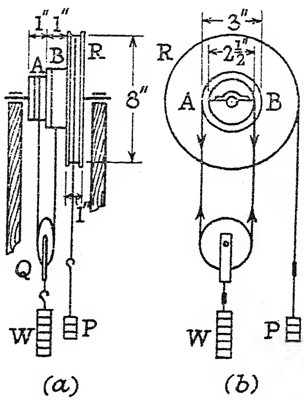


FIG. 72.
WHEEL AND DIFFERENTIAL AXLE.

Let a, b and r be the radii of A, B and R respectively. For one complete revolution of the wheel, the effort P descends a distance $2\pi r$. At the same time, the suspended portion of the string, which hangs from A and B, decreases in length by an amount equal to $2\pi b - 2\pi a$.

Thus the load W ascends a distance equal to $\frac{1}{2}(2\pi b - 2\pi a)$, i.e., $\pi b - \pi a$. Hence the velocity ratio of the machine

$$= \frac{2\pi r}{\pi(b - a)} = \frac{2r}{b - a}$$

(N.B.—The value of the velocity ratio for the model described is

$$\frac{2 \times 8''}{3'' - 2\frac{1}{2}''} \text{ i.e., } 32.)$$

The mechanical advantage of the machine is $\frac{W}{P}$. This is less than the velocity ratio, owing to the presence of friction and also to the fact that a small effort is required to raise the pulley block Q, when no load is suspended from it.

The efficiency of the machine is calculated in the usual manner from:—

$$\text{Efficiency} = \frac{\text{Mechanical advantage}}{\text{Velocity ratio}}$$

The value of the efficiency will vary according to the load, as in the other machines already described. An appliance very similar in principle is the Weston differential pulley block.

Gears

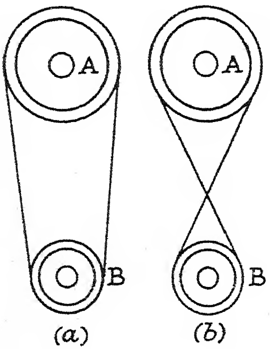


FIG. 73.
PULLEYS AND BELT.

In workshops containing a number of lathes there is one large shaft, known as the main shaft, which is run by means of a motor. This main shaft is connected to a number of counter-shafts by means of a system of pulleys and belts, and the rotation of the main shaft produces a rotation of the counter-shafts.

If A and B (Fig. (37*a*)) are pulleys, fixed to the main shaft and counter-shaft respectively, a clockwise rotation of A produces a clockwise rotation of B. If the belt is crossed (Fig. 73(*b*)), a clockwise rotation of A produces a counter-clockwise rotation of B. The pulleys A and B are known as the driver and follower respectively, and energy is thus transmitted from the main shaft to the counter-shaft.

To understand the principles involved, let us consider the simple case shown in Fig. 73(*a*).

Let d = the diameter of the pulley A (driver), fixed to the main shaft, and D = the diameter of the pulley B (follower), fixed to the counter-shaft.

n = number of revolutions per minute of A.
N = number of revolutions per minute of B.

Then the speed of a point on the circumference of A = πdn, and the speed of a point on the circumference of B = πDN.
If there is no slipping, we have:—

$$\pi dn = \pi DN, \text{ or } \frac{N}{n} = \frac{d}{D}.$$

i.e., Number of revolutions per minute of B = Number of revolutions per minute of A $\times$ $\frac{\text{Diameter of A}}{\text{Diameter of B}}$.

Speed Cones

The lathe spindle is driven from the counter-shaft by means of the speed cones A and B, connected by belting, as shown in Fig. 74. Each cone is so shaped that it really consists of three pulleys of different diameters. The lathe spindle can be run at different speeds by connecting the pulleys 1 and 4, 2 and 5, or 3 and 6. If the speed of revolution of the counter-shaft is known, the speed of the lathe spindle and therefore that of the work mounted on the face plate can be calculated in each case by employing the above formula.

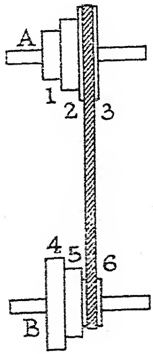


Fig. 74.
SPEED CONES.

Example. Fig. 74 shows a pair of speed cones A and B, A being fixed to the counter-shaft, which is rotating at a speed of 400 R.P.M., and B being fixed to the lathe spindle. If the diameters of the wheels are as shown below, calculate the possible speeds of revolution of the lathe spindle. (1 and 6 = 6″; 2 and 5 = 9″; 3 and 4 = 12″.)

The speeds of revolution are:—

$$\frac{12}{6} \times 400 = 800 \text{ R.P.M.}$$

$$\frac{9}{9} \times 400 = 400 \text{ R.P.M.}$$

$$\frac{6}{12} \times 400 = 200 \text{ R.P.M.}$$

Toothed Wheels

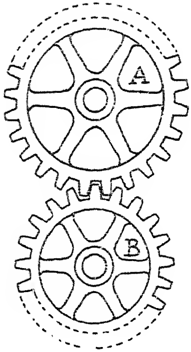


Fig. 75.

GEAR WHEELS.

It is often necessary that the different spindles of a machine should rotate with different speeds. This is done by the use of toothed wheels. Taking the case of the two wheels A and B, shown in Fig. 75, the teeth of one wheel should engage the teeth of the other along definite lines of contact. The distance between the contact line of one tooth and that of the next is the pitch, and a line passing through the centres of all the contact lines is known as the pitch circle. Now the speed of a tooth on the driver is equal to the speed of a tooth on the follower.

Hence n $\times$ circumference of pitch circle of driver $=$ N $\times$ circumference of pitch circle of follower, where n $=$ number of revolutions per minute of driver and N $=$ number of revolutions per minute of follower.

$$\text{Hence } \frac{N}{n} = \frac{\text{Circumference of pitch circle of driver}}{\text{Circumference of pitch circle of follower}}$$

$$= \frac{\text{Number of teeth in driver}}{\text{Number of teeth in follower}}$$

since the pitch is the same for each wheel.

In toothed wheels, the follower revolves in the opposite direction to the driver. Thus in Fig. 75, if A has a clockwise motion, then B has a counter-clockwise motion.

Conversion of Circular into Linear Motion

Fig. 76 shows a vice, by means of which circular motion may be converted into linear motion. A square cut screw S, which is rotated by means of the handle H, passes through a cylindrical tube C, screw threaded on the inside and attached to the movable jaw B. As the end of the vice handle, in the position

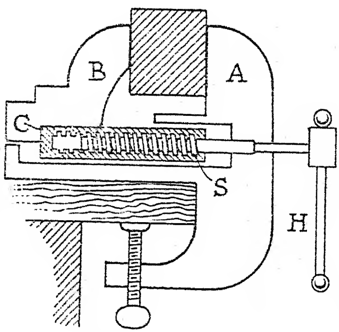


Fig. 76.

SCREW OF A VICE.

shown, moves out of the plane of the paper, the jaw B moves to the right towards the fixed jaw A. By the application of a small effort to the end of the handle, the jaws are made to exert a considerable force upon the body placed between them.

The Velocity ratio =

$$\frac{\text{Circumference of circle described by the Effort}}{\text{Pitch of Screw}}$$

Another example of the conversion of circular into linear motion is the action of the lead screw upon the carriage of a lathe.

Example. If the pitch of the lead screw of a lathe is $\frac{3}{8}$ inch, and the speed of revolution of the screw is 15 R.P.M., calculate the linear speed of the carriage.

The carriage advances $\frac{3}{8}''$ per revolution. Hence the speed of the carriage $= 15 \times \frac{3}{8} = 5{\cdot}6$ inches per minute.

Applications of Gear Wheels

Let us consider the gear wheels used in driving a car. The driving shaft and the rear axles are connected by a number of gear wheels and

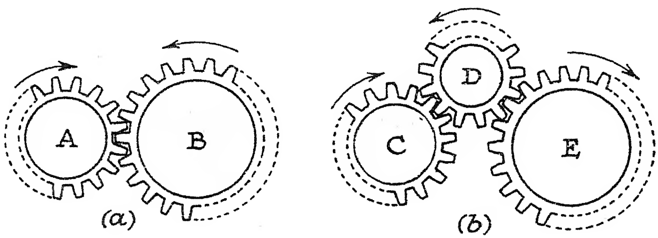


Fig. 77.

GEAR WHEELS USED IN DRIVING A CAR.

the rotation of the driving shaft produces a rotation of the rear axles. Two of the gear wheels A and B are shown in Fig. 77(*a*). A is geared to the driving shaft and B to the rear axles. If A rotates clockwise, B rotates counter-clockwise. Under these conditions let us suppose the car runs forwards.

If the car is required to run backwards it is necessary to substitute the wheels C, D and E for the wheels A and B (Fig. 77(*b*)). These additional wheels are brought into operation by the gear lever. The wheel C which is driven by the driving shaft rotates clockwise and from the diagram it can be seen that the wheel E also rotates clockwise. The car is now in reverse gear and runs backwards.

Fig. 78 shows the gear wheels which connect the spindle (mandrel) of a lathe with its lead screw. The lathe spindle and the gear wheel A rotate counter-clockwise (when viewed from the right). The wheel B rotates clockwise and the wheel C together with the lead screw D rotate counter-clockwise. Thus the carriage E which carries the cutting tool advances to the left, along the work which is mounted on the face plate F.

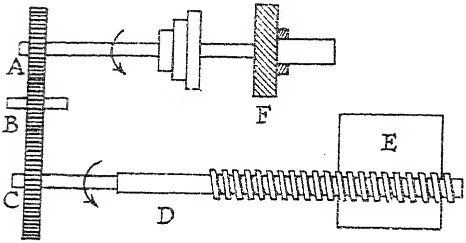


FIG 78.

GEAR WHEELS CONNECTING THE MANDREL AND LEAD SCREW OF A LATHE.

Example. The lathe spindle runs at 40 R.P.M. and the gear wheels A, B and C have 15, 10 and 75 teeth respectively. What is the speed of the carriage if the pitch of the lead screw is $\frac{3}{8}$ inch ?

$$\text{Speed of gear wheel A} = 40 \text{ R.P.M.}$$

$$\text{,, \quad ,, \quad ,, \quad ,, \quad B} = 40 \times \frac{15}{10} \text{ R.P.M.}$$

$$\text{,, \quad ,, \quad ,, \quad ,, \quad C} = 40 \times \frac{15}{10} \times \frac{10}{75} \text{ R.P.M.}$$

$$= 8 \text{ R.P.M.}$$

$$\text{Hence speed of carriage} = 8 \times \tfrac{3}{8} \text{ inches per minute.}$$

$$= 3 \text{ inches per minute.}$$

THE BACK GEARED LATHE

Fig. 79 represents the system of toothed wheels in the back gear arrangement of a lathe. A represents the speed cone which is free to rotate on the lathe spindle. B is a toothed wheel, of say 60 teeth, fixed to the lathe spindle. This wheel can be rigidly fixed to the speed cone A by means of a key K. C and D are toothed wheels fixed to another spindle, C possessing 20 teeth and D 60 teeth. E is a toothed wheel of 20 teeth, fixed to the cone A

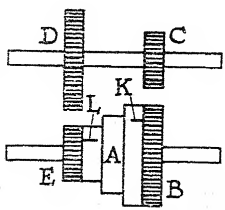


FIG. 79.

BACK GEARED LATHE.

by a key L, but free to rotate on the lathe spindle. The wheels C and D can be made to engage the wheels B and E respectively, by means of a small lever, not shown in the diagram.

When C and D are not connected to B and E respectively, and B is rigidly fixed to A, the cone A is rotated by means of the belt which connects it to the cone on the counter-shaft. The lathe spindle is then capable of running at three different speeds.

When the back gear is brought into play, additional speeds of the lathe spindle are possible. The wheel B is disconnected from the cone A, and C and D are made to engage B and E respectively, by means of the lever. The speed cone A and the wheel E, being fixed together, rotate freely on the lathe spindle. The speed of the shaft to which C and D are fixed is $\frac{20}{60}$ of that of the cone A. The speed of the wheel B, and consequently that of the lathe spindle to which B is connected, is $\frac{20}{60} \times \frac{20}{60}$, i.e., $\frac{1}{9}$ of the speed of the cone A.

Example. In the back geared lathe (Fig. 79), the speed cones on the lathe spindle and on the counter-shaft have diameters of 4, 6, 8 inches and 8, 6, 4 inches respectively.

If B, C, D and E have 60, 20, 60 and 20 teeth respectively, find the possible speeds of the lathe spindle, if the counter-shaft is rotating at 360 R.P.M.

The speeds of the cone on the lathe spindle are:—

$$360 \times \frac{8}{4} = 720 \text{ R.P.M.}$$

$$360 \times \frac{6}{6} = 360 \text{ R.P.M.}$$

$$\text{and } 360 \times \frac{4}{8} = 180 \text{ R.P.M.}$$

Hence the speeds of the lathe spindle are:—

$$720 \times \frac{20}{60} \times \frac{20}{60} = 80 \text{ R.P.M.}$$

$$360 \times \frac{20}{60} \times \frac{20}{60} = 40 \text{ R.P.M.}$$

$$\text{and } 180 \times \frac{20}{60} \times \frac{20}{60} = 20 \text{ R.P.M.}$$

Bevel Wheels

Fig. 80 shows a pair of bevel wheels. By means of this arrangement a revolving vertical spindle drives a horizontal spindle or vice-versa.

The same relationships connecting the speeds of revolution of the driver and follower apply in this case, as in the cases given above.

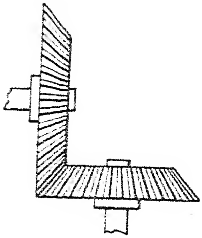


FIG. 80.

BEVEL WHEELS.

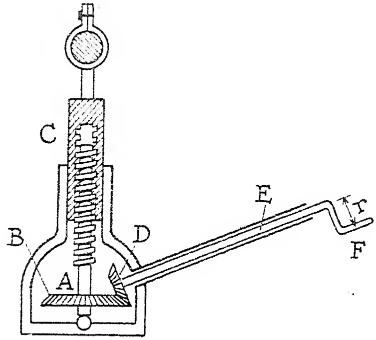


FIG. 81.

MOTOR-CAR JACK.

THE MOTOR-CAR JACK

The principle of bevel wheels is utilised in the screw jack, used for raising the axles of motor-cars. Fig. 81 shows the essential features of such a jack. A is the steel spindle which rests at its lower end on an anti-friction base. The spindle has a square cut screw along part of its length and carries a horizontal bevel wheel B. The steel block C, through which the screw of the spindle is threaded, moves freely through the upper portion of the steel casing and carries the load at its upper end. A bevel wheel D, mounted on the steel spindle E, is turned by the crank handle F and engages the wheel B. From the figure it will be seen that as the crank handle F moves out of the plane of the paper, the block C rises in the casing.

If N_B and N_D represent the number of teeth in the wheels B and D respectively, p the pitch of the spindle screw and r the radius of the circle traced out by the handle F, then for one complete revolution of the crank handle the spindle A is turned through $\frac{N_D}{N_B}$ of a revolution.

The load is therefore raised through a distance $p\,\frac{N_D}{N_B}$.

Hence the velocity ratio of the machine =

$$\frac{\text{Distance Effort moves}}{\text{Distance Load moves}}$$

$$= \frac{2\pi r}{\frac{N_D}{N_B}\,p}.$$

Exercises VII

1. Make a sketch of a three-sheave pulley block. If it is required to raise a load of 4 cwts. by means of such a tackle, what effort must be applied, assuming it to have an efficiency of 32% ?

(U. L. C. I.; B.S.)

2. Describe experiments that could be carried out with gear wheels to make clear the meaning of (*a*) mechanical advantage, (*b*) velocity ratio.

The cone pulley of a lathe in double gear makes 175 revolutions per minute. What is the mandrel speed if the teeth of the pinions are 16 and those of the wheels 50 ?

(C. G. L. I.; Hand. S.)

3. What is the difference between "velocity ratio" and "mechanical advantage" ? Show how each can be determined in (*a*) a back geared lathe, and (*b*) a small screw jack.

(C. G. L. I.; Hand. S.)

4. Speed cones are connected to a counter-shaft and to a lathe spindle (Fig. 74). The diameters of the pulleys 1, 2, 3, 4, 5 and 6 are 4, 6, 8, 8, 6, 4 inches respectively. If the counter-shaft runs at 200 R.P.M., calculate the speeds of revolution of the lathe spindle, when 1 and 4, 2 and 5, and 3 and 6 are connected by the belt.

5. Describe by briefly annotated sketches the construction of a differential pulley suitable for raising heavy weights. State suitable dimensions for the working parts and, from the figures given, estimate the velocity ratio and the mechanical advantage of the pulley. Make clear the meaning of these terms.

(C. G. L. I.; Hand. S.)

6. Explain *three* of the following:—

(*a*) The action of a bench vice with a plain square thread screw.
(*b*) The action of a spring blind roller.
(*c*) The raising of a window sash.
(*d*) A lever lock.

Point out the principles involved in each selected case.

(C. G. L. I.; Hand. S.)

7. Describe and explain the effect of gear wheels on (*a*) a hand-drill brace, (*b*) a bicycle with no variable speed gear, (*c*) a screw cutting lathe.

(C. G. L. I.; Hand. S.)

CHAPTER VIII

ELASTICITY

ELASTIC BODIES

In Experiment I, on the extension of a spring, when the load was removed the spring resumed its original length, so long as the load was not too great. The property which a body possesses, of resuming its original shape and dimensions when the force is removed, is known as elasticity. Many solids possess this property of elasticity. Thus glass, marble, iron, steel, brass, etc., are elastic bodies, whereas putty clay and even lead are inelastic. Putty, for instance, can be moulded into any shape and retains this shape even when the force is removed.

In the ordinary sense rubber appears to be more elastic than steel for instance, but in the scientific sense steel is more elastic than rubber, since steel resumes more exactly its original shape and dimensions when the force is removed.

EXPERIMENT X

To find the extension of a steel wire for different loads

A simple apparatus which can be used for this experiment is shown in Fig. 82(*a*). A steel wire, of S.W.G. 28 and 6 feet long, is supported

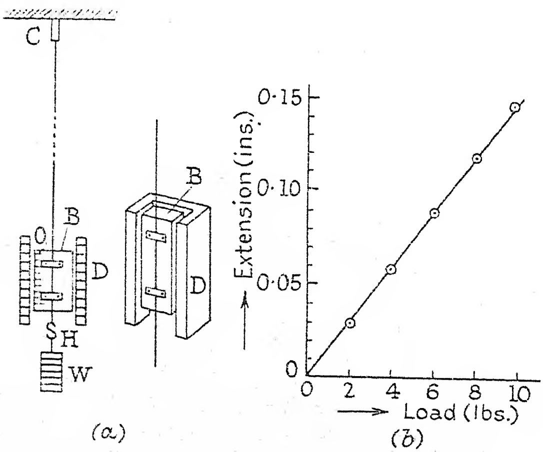


FIG. 82.
HOOKE'S LAW APPARATUS.

at its upper end by a chuck C, fixed to a wooden support in the ceiling of the laboratory. The wire carries a hook H, on which the slotted weights W are hung. Fixed to the wire is a rectangular block of wood B, $2\frac{1}{2}''$ long, $1\frac{1}{2}''$ wide and $\frac{1}{2}''$ thick, on which is marked a vernier scale. This block slides freely within a groove cut in a second wooden block D, which is mounted on brackets fixed to the wall. The standard scale, reading in inches and tenths of an inch, is marked on the block D.

Note the reading of the zero mark O of the vernier when the slotted weight carrier is suspended from the wire. Add weights of 2 lbs. in succession and note the reading of the mark O in each case. Tabulate the results and calculate the extension for each load. Now withdraw the weights one by one and again note the reading of the mark O in each case. This operation is performed in order to see whether the wire resumes its original length when the load is removed. Again tabulate the results as before. Plot a graph extension vertical and load horizontal (Fig. 82(*b*)).

Load (lbs. wt.)	Scale Reading (inches)	Extension (inches)
0	1·32	0·00
2	1·35	·03
4	1·38	·06
6	1·41	·09
8	1·44	·12
10	1·47	·15
8	1·44	·12
6	1·41	·09
4	1·38	·06
2	1·35	·03
0	1·32	·00

The graph connecting the extension and the load is a straight line, which shows that the extension is proportional to the load.

Hooke's Law

Hooke's Law states that the extension of an elastic body is proportional to the load placed upon it. All elastic materials obey this law, if the load is not too great. However, it is possible for the load to be so great that Hooke's Law breaks down; the extension ceases to be pro-

portional to the load and, in fact, increases with the load at a more rapid rate. The point at which Hooke's Law breaks down is known as the Elastic Limit. Up to this limit, the body will resume its original shape and dimensions when the load is removed, but beyond this limit the body becomes permanently extended. This permanent extension is known as the Permanent Set and in this condition the body is overstrained. In Fig. 83, AB is a straight line, which shows that the extension is proportional to the load up to the point B (the elastic limit). Beyond B the line curves upwards, which shows that the extension is greater for the same increase of load than along AB.

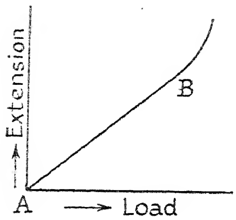


FIG. 83.
EXTENSION AND LOAD CURVE.

STRESS AND STRAIN

Suppose the rod, shown in Fig. 84, is held rigidly at the top and a force F is applied downwards at the other end. Considering the equilibrium of the portion of the rod below the section ABC, there are upward vertical forces on each element of the area. These forces tend to resist the particles along the section ABC from being pulled away from those immediately above. This distribution of forces along the cross-section is known as a stress.

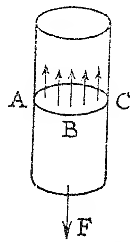


FIG. 84.
STRESS IN A SECTION OF A LOADED ROD.

The Intensity of Stress is the force or tension per unit area of section

$$\text{i.e., Intensity of Stress} = \frac{\text{Force}}{\text{Area}}$$

Thus if the area of cross section of a wire is 0·001 sq. inch and the load or tension is 10 lbs. wt., the intensity of stress

$$= \frac{10 \text{ lbs. wt.}}{0{\cdot}001 \text{ sq. inch}}$$

$$= 10{,}000 \text{ lbs. per sq. inch.}$$

The strain in a wire is the change in length per unit length, which occurs when tension is applied.

$$\text{i.e., Strain} = \frac{\text{Change in length}}{\text{Initial length}}$$

If the length of the unloaded wire is 200 inches and the increase in length when loaded $\frac{1}{10}$ inch, then the strain

$$= \frac{0 \cdot 1 \text{ inch}}{200 \text{ inches}}$$

$$= 0 \cdot 0005.$$

Young's Modulus of Elasticity

The ratio $\dfrac{\text{Intensity of Stress}}{\text{Strain}}$, in the case of change in length of a substance with increase of load, is known as Young's Modulus of Elasticity. The values of Young's Modulus for a few materials are given below.

TABLE III

Material	Young's Modulus (lbs. per sq. in.)
wrought iron	$2 \cdot 8 \times 10^7$
steel	$2 \cdot 9 \times 10^7$
brass	$1 \cdot 4 \times 10^7$
copper	$1 \cdot 8 \times 10^7$
oak	$0 \cdot 19 \times 10^7$
yellow pine	$0 \cdot 13 \times 10^7$
mahogany	$0 \cdot 13 \times 10^7$
teak	$0 \cdot 24 \times 10^7$

Phenomena beyond the Elastic Limit

If a wire consisting of a ductile* material, such as iron, is gradually loaded beyond its elastic limit, a point is reached when the material is drawn out to a considerable extent with very little increase of load. This point is called the Yield Point. The diameter of the wire decreases considerably and just before breaking point it becomes excessively thin. In non-ductile materials, such as cast iron, there is no yield point.

Tensile Strength or Breaking Stress

The tensile strength or breaking stress of a material is the breaking load per unit area.

* See Chapter XIII.

$$\text{i.e., Tensile strength} = \frac{\text{Breaking Load}}{\text{Area of Section}}$$

In the case of a rod of iron, the area of cross section of the rod becomes considerably less in the neighbourhood of the point at which it is about to break. In such cases, the load required to break the specimen is much less than the maximum load which it carries just before the area decreases. The tensile strength is calculated from this maximum and the area of section before decrease.

Example. Find the tensile stress of aluminium, if a maximum load of 31·3 lbs. wt. breaks a wire of 0·04″ diameter.

$$\text{Tensile strength} = \frac{31\cdot3 \text{ lbs. wt.}}{3\cdot142 \times (\cdot02)^2 \text{ sq. inches}}$$
$$= 24{,}900 \text{ lbs. wt. per sq. inch.}$$

Experiment XI

To compare the moduli of elasticity of two different materials in the form of wires

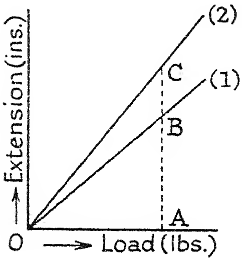


Fig. 85.
EXTENSION AND LOAD CURVES.

Obtain two wires of the same length and diameter, but consisting of two different materials. Proceed as in Experiment X, i.e., find the extensions for various loads in the case of each wire. Plot extension against load for each wire, as in Fig. 85.

Now for the load OA, one wire increases in length by AB and the other by AC.

Let L = the unstrained length of each wire. Then:

$$\frac{\text{Young's Modulus of Elasticity for wire (1)}}{\text{Young's Modulus of Elasticity for wire (2)}}$$

$$= \frac{\text{Force per unit area for wire (1)}}{AB/L} \div \frac{\text{Force per unit area for wire (2)}}{AC/L}$$

$$= \frac{AC}{AB}$$

The ordinate ABC may be drawn for various loads, and hence several values for the ratio may be determined.

The Bending of a Beam

If a beam AB is clamped to the table (Fig. 86) and loaded at the free end, it assumes a curved shape. If we consider the beam (a section of which is shown inset) to be divided into filaments parallel to its length, the filaments in the upper portion are extended and those in the lower portion compressed. There is a surface, viz., the surface through EF at right angles to the plane of the paper, along which the filaments are neither compressed nor extended. Now a beam, composed of a substance of high elastic modulus, is extended a smaller amount for a given tension than one of the same dimensions, composed of a substance of low elastic modulus. Thus the beam, made of a substance of high elastic modulus, is bent less for a given load than the one made of a substance of low elastic modulus and consequently the depression of the free end of the former is less than the depression of the free end of the latter.

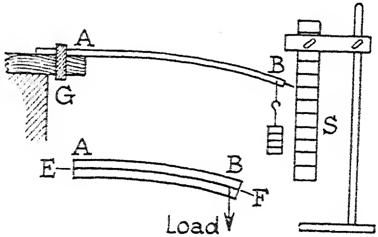


Fig. 86.
MODULUS OF ELASTICITY BY BENDING APPARATUS.

The elastic modulus of bending varies inversely as the depression. Thus, if d represents the depression and E the elastic modulus of bending, we have:—

$$E \text{ varies as } 1/d.$$

The proof of this relation may be found in more advanced textbooks.

Experiment XII

To compare the elastic moduli of bending of two wooden rods of equal dimensions, but composed of different materials

Take two wooden rods, composed of different timbers and of exactly the same dimensions, e.g., 3 feet by $\frac{1}{2}$ inch by $\frac{1}{4}$ inch. Clamp one rod to a table by means of a clamp G (Fig. 86), so that 3 inches of the rod are in contact with the table top. Support an inch scale S vertically, at about half an inch from the end of the rod. Insert a pin into the end of the rod, to act as an indicator. Note the position of the indicator on the scale when the rod is unloaded. Now hang a 1 lb. wt. from a point $\frac{1}{4}$ inch from the free end of the rod and note the reading of the indicator on the scale. Thus find the depression for 1 lb. wt.

Repeat the experiment with the second rod, arranged under exactly the same conditions as in the first case, and again find the depression for 1 lb. wt. Calculate the ratio of the elastic moduli of bending from the formula given below:—

If d_1 = depression of the end of 1st rod, and d_2 = depression of the end of 2nd rod, we have:—

$$\frac{\text{Elastic modulus of bending of rod (1)}}{\text{Elastic modulus of bending of rod (2)}}$$

$$= \frac{\dfrac{1}{d_1}}{\dfrac{1}{d_2}} = \frac{d_2}{d_1}$$

Exercises VIII

1. Devise simple experiments to compare the elasticities of (*a*) two metal wires of different composition, and (*b*) two wooden lathes each about a yard in length.

(C. G. L. I.; Hand. S.)

2. If a square steel bar is required to carry a load of 3 tons, allowing a safe tensile stress of 7 tons per sq. inch, determine the thickness of the bar.

3. If the tensile stress of a material has not to exceed 4·5 tons per square inch, determine the diameter of a tie rod of circular section which has to resist a pull of 25 cwts.

4. A wire was suspended from a roof beam and subjected to gradually increasing loads with the following results:—

Load (W) lbs. ..	6	12	18	24	30	36	42	48	54
Extension (*e*) ins...	0·14	0·28	0·42	0·56	0·74	0·84	1·06	1·30	1·61

Plot a graph showing the relation between the extension and the load and explain the significance of any peculiarity in the shape of the graph.

(U. L. C. I.; B.S.)

5. A steel column 18 ft. long is found to contract ·12 inch when bearing a load of 30 tons. If the area of the cross section is $4\frac{1}{2}$ sq. inches, find the measure of the stress and the strain per inch of length.

(U. L. C. I.; B.S.)

6. Describe a method of comparing the elasticities of two strips of wood of similar dimensions but different timbers.

(C. G. L. I.; Hand. S.)

7. By reference to metals commonly used in constructional work, illustrate two of their characteristic properties capable of being measured accurately. In each case describe briefly the method of measurement.

(C. G. L. I.; Hand. S.)

CHAPTER IX

HYDROSTATICS (A)

Thrust and Pressure

Consider a vessel with various holes in its sides and base, each hole being fitted with a plug. If the vessel is filled with water, a force will have to be applied at each plug, whatever its position, in order to prevent the water from running out. Hence the water exerts a thrust on every portion of the surface with which it is in contact.

Pressure

Pressure is a distribution of thrust over a surface and is measured by the amount of thrust per unit area of a plane exposed to it.

Uniform Pressure

A pressure is uniform when the force on each unit of area is the same.

$$\text{i.e., Pressure} = \frac{\text{Thrust}}{\text{Area}}$$

Thus, if a thrust of 300 lbs. wt. is distributed uniformly over a surface of area 20 sq. inches, the pressure is 15 lbs. per sq. inch.

Example. A tank, measuring 3 feet by 2 feet, contains water to a depth of $1\frac{1}{2}$ feet. Find (*a*) the thrust on the base and (*b*) the pressure in lbs. per sq. inch. (1 cub. ft. of water weighs $62\frac{1}{2}$ lbs.).

$$\begin{aligned}
(a)\ \text{Thrust} &= \text{Total force acting on base.} \\
&= \text{Weight of water in tank.} \\
&= \text{Volume} \times \text{Density.} \\
&= (3 \times 2 \times 1\tfrac{1}{2})\ \text{cub. ft.} \times 62\tfrac{1}{2}\ \text{lbs. per cub. ft.} \\
&= 9 \times 62\tfrac{1}{2} = 562{\cdot}5\ \text{lbs. wt.}
\end{aligned}$$

$$\begin{aligned}
(b)\ \text{Pressure} &= \frac{\text{Thrust}}{\text{Area}} = \frac{562{\cdot}5\ \text{lbs. wt.}}{3 \times 2 \times 144\ \text{sq. inches.}} \\
&= 0{\cdot}65\ \text{lb. per sq. inch.}
\end{aligned}$$

Transmissibility of Pressure

Experiment XIII

Bore a hole, about $\frac{1}{8}$ inch in diameter, in a hollow rubber ball and fill the ball with water. Place the finger over the hole and, by means of a pin, prick several small holes in the ball, at right angles to its surface. Now squeeze the ball, when water will issue from each hole radially. The experiment shows that the pressure has been transmitted equally in all directions.

Pressure due to a Column of Liquid

Consider a column of liquid (Fig. 87), of uniform cross sectional area A and vertical height h. Let the density of the liquid be d. Then, since the thrust on the base is equal to the weight of the column, we have:—

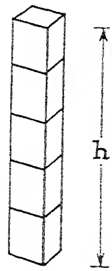


Fig. 87.
PRESSURE DUE TO A COLUMN OF LIQUID.

$$\text{Pressure due to the column of liquid} = \frac{\text{Weight}}{\text{Area of base}}$$

$$= \frac{\text{Volume} \times \text{Density}}{\text{Area of base}}$$

$$= \frac{Ah \times d}{A}$$

$$= hd.$$

$$\text{Thus: Pressure} = \text{Height} \times \text{Density}$$

$$\text{(lbs. per sq. inch)} = \text{(inches)} \times \text{(lbs. per cub. inch)}.$$

Or in the metric system,

$$\text{Pressure} = \text{Height} \times \text{Density}$$

$$\text{(grams per sq. cm.)} = \text{(cm.)} \times \text{(grams per c.c.)}.$$

Experiment XIV

To investigate the relationship between the pressure at a depth in a liquid and the depth

Prepare a cylindrical rod of wood, about 20 cm. long and 2·5 cm. in diameter. Drill a hole into it, about 17 cm. long and 1 cm. in diameter. Paste a strip of squared paper, reading in cm., along its length. Measure the diameter of the rod by means of a pair of calipers and calculate the area of cross section. After weighing the rod, allow

it to float in a large measuring cylinder containing water (Fig. 88(*a*)). Since the solid end of the rod is in the water, it floats upright. Note the length of the rod immersed. Now place a known weight of lead shot in the cavity and again note the length immersed. Repeat the experiment for various weights of lead shot and tabulate the results as below:—

Wt. of rod + shot W (grams)	Area of Section A (sq. cm.)	Pressure $=\frac{W}{A}$ (grams per sq. cm.)	Depth (cm.)
15·33	1·94	7·9	8·1
16·88		8·7	8·8
18·36		9·5	9·4
19·94		10·3	10·1
21·52		11·1	11·2
22·10		11·4	11·5

Plot a graph connecting the pressure and the depth (Fig. 88(*b*)).

In the above experiment, the forces acting on the rod are (1) the weight of the rod, etc., acting vertically downwards, (2) the upthrust of the liquid on the base and (3) the horizontal thrusts of the liquid on its vertical sides. Since the rod is in equilibrium, the weight of the rod, etc., is equal to the upthrust of the liquid on the base and the horizontal thrusts on the vertical sides balance each other.

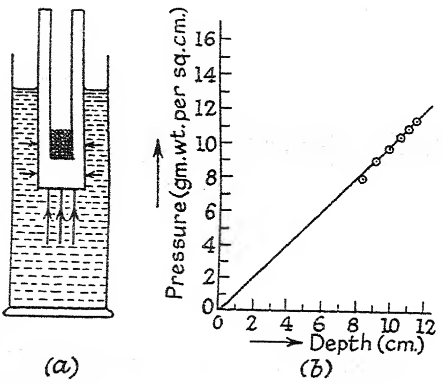


FIG. 88.

APPARATUS FOR DETERMINING THE PRESSURE AT A DEPTH IN A LIQUID.

The graph connecting the pressure at a depth and the depth is a straight line, which shows that the pressure at a point in a liquid is proportional to the depth of the point below the surface of the liquid.

Thus: Pressure = Depth × Density.

Archimedes' Principle

Suppose ABCD (Fig. 89) represents a block of iron of uniform cross sectional area 1 sq. cm. and length 5 cm. Let the block be immersed in water, and let it be supported by a string. Then:—

Upthrust on BC = 6 grams wt.

(N.B.—1 c.c. of water weighs 1 gram.)

Downward thrust on AD = 1 gram wt.

∴ Resultant upthrust on the block = 5 grams wt. Also the weight of the water displaced = 5 grams wt. Thus the upthrust on the block is equal to the weight of the water displaced.

Again suppose EFGH represents a block of wood of the same dimensions. The block floats in equilibrium and we have:

Upthrust on FG = 4 grams wt. and weight of water displaced = 4 grams wt.

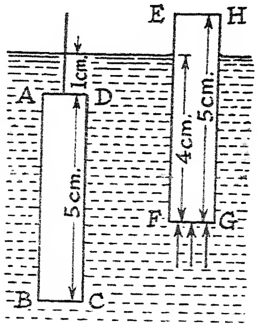


Fig. 89.

UPTHRUST ON A SOLID IMMERSED IN A LIQUID.

Thus the upthrust on the solid in each case is equal to the weight of the water displaced.

Experiment XV

To verify Archimedes' Principle

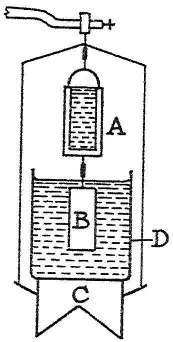


Fig. 90.

APPARATUS FOR VERIFYING ARCHIMEDES' PRINCIPLE.

The apparatus used in this experiment consists of a hollow brass cylinder A, about 6 cm. long, into which a solid brass cylinder B just fits. The solid cylinder is suspended from a hook in the lower face of the hollow cylinder (Fig. 90). The two cylinders are then suspended from the hook which supports one of the pans of a common balance. Weights are placed on the other pan until balance is obtained. The solid cylinder is now immersed in water, contained in a beaker D which stands on a wooden bridge C. (N.B.—The pan of the balance must be quite free.) Balance is now disturbed.

Fill the hollow cylinder with water by means of a pipette. When this is done, balance is restored. Repeat the experiment with a liquid such as par-

affin, when the same result will be obtained. Now since the internal volume of the hollow cylinder is equal to the volume of the solid cylinder, the weight of liquid displaced by the solid cylinder is equal to the upthrust upon it.

EXPERIMENT XVI

To compare the weight of a floating solid with the weight of the water it displaces

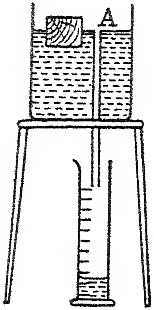


FIG. 91.
DISPLACEMENT VESSEL.

Weigh a block of wood 3″ by 2″ by 1″ on a common balance. Place the block in a displacement vessel, standing on a tripod and containing water up to the end A of the exit tube (Fig. 91). Collect the displaced water in a measuring vessel. Now determine the weight of the displaced water (1 c.c. weighs 1 gram) and compare with the weight of the block. These weights will be found to be approximately equal.

The above experiments verify the law known as Archimedes' Principle, which may be stated:—

If a body is wholly or partially immersed in a liquid, it is buoyed up with a force which is equal to the weight of the liquid displaced.

EXPERIMENT XVII

To determine the relative density of a solid which sinks in water

Support the solid (e.g., a piece of iron) from a string attached to a spring balance which reads to 250 grams in grams. Note the reading of the balance. Now immerse the solid in water contained in a beaker, and again note the reading of the balance. Tabulate the results as below and calculate the relative density of the solid.

Weight of solid in air	=	127 grams
Apparent weight of solid in water	=	110 ”
Upthrust	=	17 ”
∴ Weight of water displaced	=	17 ”
∴ Weight of an equal volume of water	=	17 ”

$$\text{Hence R.D. of solid} = \frac{\text{Weight of Solid}}{\text{Weight of an equal volume of water}}$$

$$= \frac{127 \text{ grams}}{17 \text{ grams}} = 7{\cdot}5.$$

EXPERIMENT XVIII

To find the relative density of a liquid (e.g., paraffin)

In this experiment, a common balance may be used. Suspend a solid, e.g., a glass stopper, from one arm of the balance, by means of a piece of cotton thread (Fig. 92) and determine the weight of the solid. Now allow the solid to hang freely in a beaker containing water and standing on a bridge. See that the balance pan is quite free and determine the apparent weight of the solid in water. Repeat the experiment with paraffin in the beaker and tabulate the results as below:—

Wt. of solid in air	=	39·45	grams.
Apparent wt. of solid in water	=	23·86	,,
Apparent wt. of solid in paraffin	=	26·97	,,
Apparent loss of wt. of solid in water	=	15·59	,,
Apparent loss of wt. of solid in paraffin	=	12·48	,,
∴ Wt. of water displaced	=	15·59	,,
and wt. of paraffin displaced	=	12·48	,,

$$\therefore \text{R.D. of paraffin} = \frac{\text{Wt. of paraffin displaced}}{\text{Wt. of water displaced}}$$

$$= \frac{12{\cdot}48 \text{ grams}}{15{\cdot}59 \text{ grams}} = {\cdot}80.$$

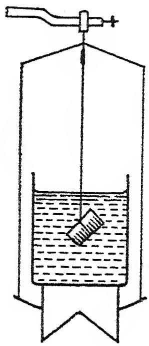


FIG. 92.
RELATIVE DENSITY BY ARCHIMEDES' PRINCIPLE.

FLOATING BODIES

If a block of iron is held with its lower face in the surface of water and released, the block moves downwards into the water and continues to move downwards, even when fully immersed, because the upthrust, or weight of water displaced, is less than the weight of the block. If, on the other hand, a block of wood is held with its lower face in the surface of water and released, the block moves downwards until the weight of water displaced or the upthrust becomes equal to the weight of the block. In this case, the block of wood attains a position of equilibrium with a portion of its volume outside the surface of the water.

Let us consider the case of a uniform rod of wood which floats in water. (Fig. 93.) Suppose L is the length of the rod and l the length immersed in water. Then:—

$$\text{Relative Density of the wood} = \frac{\text{Weight of rod}}{\text{Wt. of equal volume of water}}$$

$$= \frac{\text{Wt. of water equal in volume to BCED}}{\text{Wt. of water equal in volume to ABDF}}$$

$$= \frac{l}{L} = \frac{\text{Length immersed}}{\text{Total Length}}$$

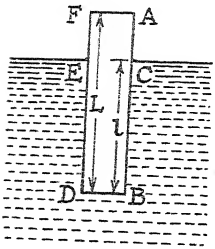


FIG. 93.
RELATIVE DENSITY OF A FLOATING SOLID.

The Common Hydrometer

Fig. 94(*a*) shows a common hydrometer which is used for measuring the relative densities of liquids such as oils, sulphuric acid, etc. B is a glass bulb containing a quantity of mercury, and AE is the hollow glass stem which is graduated to read relative densities directly. Since a greater length of a floating body is immersed in a liquid of smaller relative density, the hydrometer is graduated downwards. Thus c (1,000) represents the point to which the hydrometer sinks in pure water and d (1,200) is the point to which it sinks in sulphuric acid of R.D. 1·2. The space between c and d is divided into 200 equal divisions, so that the relative density of a liquid may be determined to three decimal places. Thus, if the hydrometer sinks to the mark f (1,165), the relative density of the liquid is 1·165.

Hydrometers are used for measuring the relative density of sulphuric acid in accumulators. This test serves as an indication as to whether the accumulator requires recharging. When making a test, an instrument such as the one shown in Fig. 94(*b*) is used. The hydrometer A is enclosed in a vessel B which terminates in a narrow tube C. A hollow rubber ball D fits airtight on the neck of the vessel. The tube C is immersed in the acid and, when the ball is squeezed and released, acid is drawn into the vessel. The hydrometer now floats and its reading can be taken.

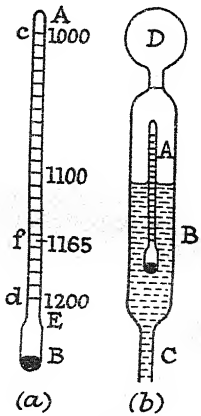


FIG. 94.
COMMON HYDROMETER.

The Hydraulic Press

The principle of this machine depends on the fact that a liquid transmits a pressure equally in all directions. A is the plunger of a

force pump (Fig. 95). This pump, the principle of which will be discussed in a later chapter, lifts water from a tank D and drives it into a cylinder C, fitted with a large plunger B. If the area of cross section of the small plunger is 1 sq. inch and that of the large plunger 50 sq. inches, and a force of 5 lbs. wt. is applied to the small plunger, then a pressure of 5 lbs. wt. per sq. inch is transmitted to the large plunger. Thus the upward thrust on the large plunger is 50×5 or 250 lbs. wt.

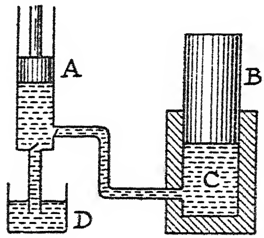


FIG. 95.
HYDRAULIC PRESS.

If a and b are the areas of cross section of the small and large plungers respectively and f and F are the corresponding thrusts, the pressure transmitted from the small to the large plunger

$$= \frac{f}{a}$$

But the pressure on the large plunger

$$= \frac{F}{b}$$

$$\text{Hence } \frac{F}{b} = \frac{f}{a}$$

$$\therefore F = f\,\frac{b}{a}$$

$$\text{i.e., } \frac{\text{Thrust on large}}{\text{plunger B}} = \frac{\text{Thrust on small}}{\text{plunger A}} \times \frac{\text{Area of large plunger B}}{\text{Area of small plunger A}}$$

Thus by means of a small effort, applied to the small plunger, a large load can be raised by the large plunger. This can be effected only by causing the effort to move through a correspondingly large distance.

Exercises IX

1. Upon what factors does the pressure of a liquid at a point below the surface depend?

Describe one way of measuring the upward pressure of water per square inch on an area 1 ft. below the surface of the water.

(C. G. L. I.; Hand. S.)

2. Describe in detail an experimental method for finding the density of a small piece of wood.

Show how the result could be used in estimating the weight of one hundred pieces of the same sort of wood, each measuring 6 ft. in length, 6 ins. in width and 2 ins. in thickness.

(C. G. L. I.; Hand. S.)

3. Describe experiments which you would make in order to determine (*a*) the specific gravity of benzene, (*b*) the specific gravity of a brass weight.

(C. G. L. I.; Hand. S., part question.)

4. (*a*) State the Principle of Archimedes.

(*b*) Explain why a piece of ice floats.

(*c*) A raft made of wood of density 480 ozs. per cubic foot floats in fresh water. Its volume is 12 cubic feet. What weight can be placed *on* it so that it will just sink? The density of fresh water is 1,000 ozs. per cubic foot.

(U. L. C. I.; P. S. T.)

5. A block of wood weighing 20 lbs. floats in water with 3/5 of its volume immersed.

(*a*) What is the relative density of the wood compared with water?

(*b*) What weight must be placed on the wood in order that the top surface of the wood shall be just level with the surface of the water?

(U. L. C. I.; P. S. T.)

6. State "Archimedes' Principle" of Buoyancy.

A body weighs 62·6 grams in air, 38·8 grams in water, and 34·4 grams in a solution. Find the specific gravity of the body and also of the solution.

Find from your results the weight of 1 cubic foot of the solution, given that 1 cubic foot of water weighs 1,000 ozs.

(U. L. C. I.; P. S. T.)

7. Explain, with a suitable diagram, the working of a direct acting hydraulic lift.

In such a lift, the ram is 3 in. in diameter and has a stroke of 12 feet. If the water is supplied under a pressure of 700 lbs. weight per square inch, what total weight can be raised, neglecting friction? How much work is done in raising the load?

(C. G. L. I.; Hand. S.)

CHAPTER X

HYDROSTATICS (B)

The Atmosphere

Surrounding the earth, there is a gaseous covering which is known as the atmosphere or the air. Although the air is invisible, its presence is made apparent by its action on solid bodies. Thus everyone is acquainted with the effect of wind, which is really moving air.

The following experiments serve to show that air exerts a pressure.

Experiment XIX

To show that the atmosphere exerts a pressure in all directions

Procure a thin tin can, having an exit tube which is fitted with a piece of rubber tubing and a clip. Remove the clip and boil a small quantity of water in the can. The air is driven out and the can becomes filled with steam. Now clip the tubing, and after a few minutes the can collapses. The explanation is as follows. The steam inside condenses to a small volume of water. Since the air pressure inside is removed and the pressure of the atmosphere acting on the outside is the same, the sides of the can are forced inwards.

Experiment XX

To show that the air exerts an upward pressure

Take a tumbler AB and fill it to the brim with water. Place half a sheet of foolscap over the top. Press the paper tightly to the tumbler and avoid leaving any air bubbles in the water. When the tumbler is inverted (Fig. 96) the paper is not forced down by the water. This experiment shows that the air exerts an upward pressure, which is greater than the downward pressure of the column of water AB.

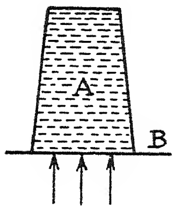


Fig. 96.
UPWARD PRESSURE DUE TO THE ATMOSPHERE.

Experiment XXI

To show that the atmosphere exerts a pressure downwards (The Mercurial Barometer)

Take a thick glass tube A, closed at one end, about 36 inches long and $\frac{1}{4}$ inch in internal diameter. Fill the tube with clean mercury,

taking care to get rid of all air bubbles. This may be done by placing the thumb over the open end, inverting the tube a few times until the air bubbles collect into one large bubble, and then pouring more mercury into the space left. Now place the thumb over the open end and invert the tube with this end under the surface of mercury, contained in a dish. Then support the tube vertically in a stand (Fig. 97).

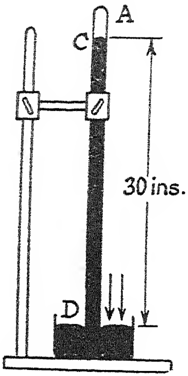


FIG. 97.
TORRICELLIAN BAROMETER.

The mercury in the tube falls until it stands at a definite level C, leaving a space at the top of the tube. This space is free from air and is called a vacuum. If the height of the column of mercury above the mercury surface in the dish is measured, it is found to be approximately 30 inches. Since there is no air pressure in the vacuum, the pressure due to the column of mercury CD must be balanced by the downward pressure of the air on the surface of the mercury in the dish. Thus the atmospheric pressure acts vertically downwards and is equivalent to the pressure due to a vertical column of mercury approximately 30 inches long.

Calculation of the Pressure due to the Atmosphere

The pressure of the atmosphere may be calculated in the following manner:—

$$\text{Wt. of 1 cub. ft. of water} = 62{\cdot}5 \text{ lbs. wt.}$$

$$\therefore \text{Wt. of 1 cub. inch of water} = \frac{62{\cdot}5}{1728} \text{ lbs. wt.}$$

$$\therefore \text{Wt. of 1 cub. inch of mercury} = \frac{62{\cdot}5}{1728} \times 13{\cdot}6 \text{ lbs. wt.,}$$

since the relative density of mercury is 13·6.

Hence the pressure of the atmosphere

$$= \text{height} \times \text{density}$$

$$= 30(\text{inches}) \times \frac{62{\cdot}5}{1728} \times 13{\cdot}6 \text{ (lbs. wt. per cub. inch)}$$

$$= 14{\cdot}7 \text{ lbs. wt. per sq. inch.}$$

THE SIPHON BAROMETER

Figs. 98(*a*) and (*b*) show a model of a siphon barometer in front and side elevation. AB is a U tube of $\frac{1}{4}''$ bore, the longer arm being 36″ long and closed at the end A, and the shorter arm 6″ long and open at the end B. A quantity of clean mercury is poured into the tube and, by inverting the tube a few times with the thumb on the open end, the air is withdrawn from the closed end. Thus when the tube is in an upright position, the mercury rises to the end A and no air space is left. More mercury is then added and the mercury in the longer branch falls, leaving a vacuum at the top. The tube is fastened to the stand by means of screw clips X and Y. A scale about 36″ long, 1″ wide and $\frac{3}{16}''$ thick, and reading in inches and tenths of an inch, is screwed to the stand so as to be equidistant from the two limbs of the U tube.

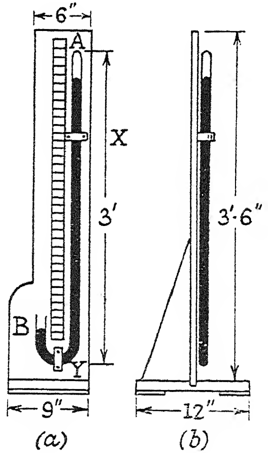


FIG. 98.

MODEL OF A SIPHON BAROMETER.

The mercury levels are read off from the scale and the difference represents the barometer reading at the time the apparatus is constructed. Any subsequent alteration in the atmospheric pressure produces a corresponding change in the mercury levels in the two branches of the tube.

THE ANEROID BAROMETER

The aneroid barometer, which will now be described, has the important advantage of portability which the mercury barometer does not possess. The essential features of an aneroid barometer are shown in Fig. 99. A is a flat cylindrical box, made of thin corrugated metal and fixed to the base plate of the instrument. The box is exhausted of air as far as possible, so that the flexible top and bottom move slightly in and out with slight changes of atmospheric pressure. One end of a stout

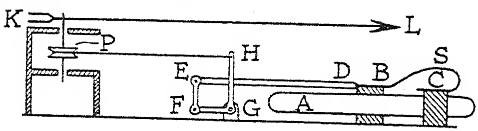


FIG. 99.

ANEROID BAROMETER.

flat spring S is attached to the top of the box at B and the other end is secured to a support C. A rod DE, fixed to the spring S, communicates any rise or fall of the upper face of the box to a lever system EFGH. This system consists of a thin rod EF, one end of which is pinned to the end of the rod DE and the other end to a bent lever FGH, pivoted at G. One end of a thin chain is connected to the end H of the lever and the other end of the chain is wrapped round a small pulley P, fixed to the spindle which carries the pointer KL. A fine hair spring (not shown in the diagram), secured at one end to a support and at the other end to the spindle, keeps the chain taut.

If the atmospheric pressure increases, the upper face of the box is forced inwards and the end E of the rod DE is depressed. The end F of the bent lever moves down and the end H moves to the left. Thus the end L of the pointer (in the position shown) moves out of the plane of the paper. A scale is attached to the instrument. This scale, along which the pointer moves, is graduated to read atmospheric pressures in inches of mercury.

Experiment XXII

To show the effect of (a) increased pressure and (b) reduced pressure on the mercury surface of a siphon barometer

Attach a piece of rubber tubing to the end B of the siphon barometer (Fig. 98). Place the free end of the rubber tubing in the mouth and blow air into the tube. The difference in level between the two mercury surfaces increases. Now withdraw air from the tube by suction. The difference in level between the surfaces decreases.

The Standard Barometric Height

From the preceding experiment it can be seen that if the pressure on the surface of the mercury alters, the length of the mercury column alters also. Now the length of the air column which acts on a barometer at sea level is greater than that at the top of a mountain. Consequently the pressure of the atmosphere and the length of the mercury column are greater at sea level than at the more elevated point.

Apart from the fact that the atmospheric pressure is different at different altitudes, the atmospheric pressure at any particular place varies slightly from day to day. Thus if we wish to speak of a pressure of one atmosphere, we must specify a definite length of mercury column. This length is 76 cm. and the Standard Atmospheric Pressure may be defined as the pressure due to 76 cm. of mercury.

The Bourdon Gauge

The Bourdon gauge (Fig. 100) is a familiar type of instrument for measuring pressures. FA is a steel tube of elliptical section, bent in circular fashion, with the end A closed and the other end F fitting air-tight into the entrance tube XY. The end X of this entrance tube is screw cut, which allows it to be screwed on to the vessel containing the fluid whose pressure is required. The pressure of the fluid is transmitted to the air in FA and tends to straighten it out, causing the end A to move outwards. A connecting rod joins A to the end B of a lever, pivoted at C, the other end of the lever being attached to a portion of a toothed wheel D. This engages another toothed wheel E which revolves about an axis coincident with the centre of the gauge. A pointer P, fixed to the wheel E, moves along a circular scale marked in lbs. per sq. inch. The figure shows that, as the end A moves outwards the wheel D revolves in a counter-clockwise direction and the wheel E in a clockwise direction.

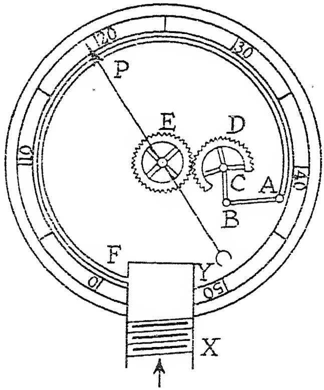


Fig. 100.
BOURDON GAUGE.

Direct pressure reading gauges, of a similar type to the Bourdon gauge, are used in conjunction with the hydraulic press in the Brinell hardness testing machine and also with the boilers of steam-engines.

Boyle's Law

Experiment XXIII

To investigate the relationship between the volume and pressure of a given quantity of air at constant temperature

The model used in this experiment may be constructed by the student. Figs. 101(*a*) and (*b*) show the front and side elevations, with suitable dimensions. AB is a piece of glass tubing, 15″ long and $\frac{1}{4}''$ bore, closed at the end A and connected to a piece of pressure tubing (thick-walled rubber tubing), 30″ long and $\frac{3}{16}''$ in internal diameter. The other end of the pressure tubing is connected to a piece of glass tubing, 15″ long and $\frac{1}{4}''$ in internal diameter, and open at the end C. The tube AB is fixed to the wooden stand by means of screw clips X

and Y, and the tube CD is fixed to a wooden slider S (3″, 2″, ¼″), by means of the screw clips Z and W (Fig. 101(*c*)). A bolt, fixed to the slider, passes through a narrow chase (Fig. 101(*d*)) in the wooden support and the slider is fixed in position by means of a wingnut at the back. A metre scale PQ is fixed vertically on the stand and the slider can be moved along it into any desired position.

Before the tubes are fixed in position on the stand, clean mercury is poured into the tube CD, and by alternately raising and lowering this

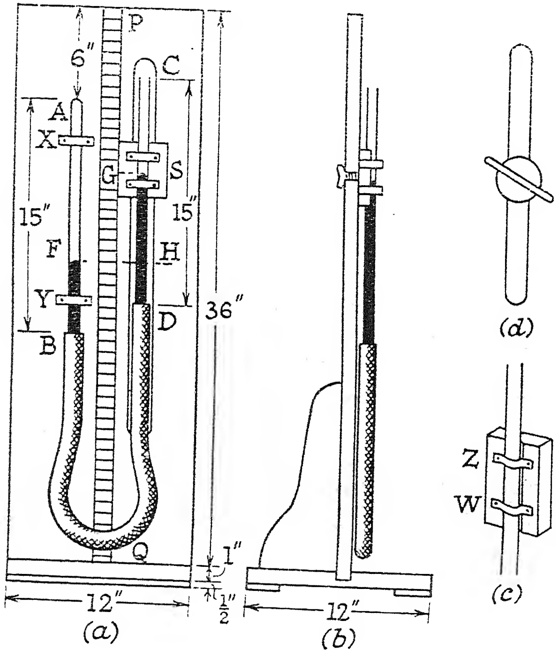


FIG. 101.

APPARATUS FOR VERIFYING BOYLE'S LAW.

tube air is withdrawn from the tube AB until the mercury level reaches the point F, about 5″ from B. The tubes are then fixed in their positions and the model is ready for use.

To perform an experiment, fix the slider S in position and measure the length of the air column AF and the excess pressure GH by means of the scale attached to the stand. Read the height of the barometer and calculate the pressure of the air in the tube AB. This is done as follows:—

Pressure of enclosed air at F = Pressure at H, since FH is horizontal, i.e., Pressure of air in AF = Atmospheric pressure + Excess pressure GH. Repeat the experiment and tabulate the results as below:—

Length of air column (l) cm.	Atmospheric pressure (p) cm.	Excess pressure (p_1) cm.	Total pressure $P = p + p_1$ cm.	Pressure × Length AF = Pl
20·3	75·5	0	75·5	1533
19·2		4·4	79·9	1534
18·0		10·0	85·5	1539
16·7		16·3	91·8	1533
21·8		− 5·3	70·2	1530
23·8		−11·0	64·5	1535

Allowing for errors in the experiment, the product Pl is a constant.

i.e., Pl = a constant.

But V = l × a constant, where V = the volume of the enclosed air.

∴ PV = a constant.

If a thermometer, placed by the side of the tube AB, is read at intervals during the experiment it will be found that the temperature remains practically unaltered.

The above law, which has been verified for air, is true for all gases. The law was discovered by Boyle and may be stated as follows:—

The volume of a given quantity of any gas varies inversely as its pressure, provided the temperature remains constant.

Example. A given quantity of a gas occupies a volume of 30 cubic feet under atmospheric pressure, which is 14·7 lbs. per sq. inch. What pressure will the gas exert if it is compressed to a volume of 7·5 cubic feet, assuming the temperature to be constant?

We have PV = c, where P is the pressure of the gas, V the volume and c a constant.

$$\therefore 14{\cdot}7 \times 30 = c.$$

But the final volume = 7·5 cubic feet.

Hence the final pressure is given by—

$$P \times 7{\cdot}5 = 14{\cdot}7 \times 30$$

$$\therefore P = \frac{14{\cdot}7 \times 30}{7{\cdot}5} = 58{\cdot}8 \text{ lbs. per sq. inch.}$$

The Pneumatic Tank

In buildings where the pressure of the water supply is very small, it is difficult to obtain water on the upper floors. This difficulty is overcome by the use of a pneumatic tank (Fig. 102), which consists of a steel airtight cylinder A, with an inlet for water at X and an outlet at Y. Water is pumped into the supply pipe at the inlet valve V and forced into the tank. The volume of the air space in the upper part of the tank is reduced, with a consequent increase in the pressure of the air (Boyle's Law). When this pressure is great enough a column of water is maintained in the pipe B, of a sufficient height to reach the upper floors.

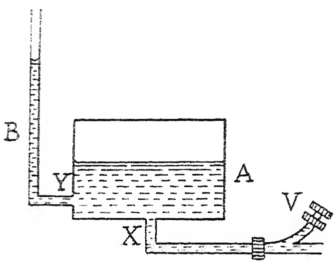


FIG. 102.
PNEUMATIC TANK.

The Simple Bellows

Fig. 103 shows a pair of bellows used for driving a strong current of air into a fire. B is a fixed pear-shaped board, A is a movable board hinged at C, and L is the leather casing, fastened to the boards as shown. The fixed board B possesses a valve V which opens inwards. The action of the bellows is as follows. As A is depressed by the handle attached to it the valve V closes, since the pressure inside the bellows becomes greater than the pressure outside.

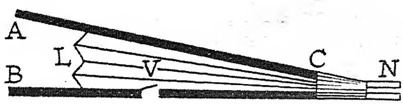


FIG. 103.
SIMPLE BELLOWS.

A current of air is driven through the nozzle N which is fitted with a non-return valve. When the board A is raised the air inside the chamber expands and its pressure becomes less than atmospheric. The valve V opens and air rushes in from outside. On again depressing the board A a current of air is again driven through the nozzle N and the operation is repeated.

The Double-Acting Bellows

When a strong blast of air is required continuously the bellows described above are unsuitable, owing to the fact that the current is

intermittent. Air is forced through the nozzle N only during the downward stroke of A. To obtain a continuous current of air the double-acting bellows, shown in Fig. 104, are used. This consists of two air chambers instead of one. C is a fixed board with a valve V_1 opening upwards, B is a movable board also possessing a valve V_2 opening upwards, and D is a movable board pressed down by a weight W_1. The board B, to which is attached a weight W_2, is raised by a system of chains attached to the end N of a lever LN, pivoted at O. On depressing the end L, the board B rises and the air in the lower chamber is compressed, thus closing the valve V_2. At the same time, the valve V_1 opens and air rushes into the upper chamber, raising the board D and also issuing through the nozzle A. The lower board B is now depressed by the weight W_2, the air in the lower chamber expands and its pressure decreases. Thus the valve V_2 opens and air rushes in from the outside. During this operation, the weight W_1 depresses the board D. The air in the upper chamber is compressed, the valve V_1 closes and compressed air is driven through the nozzle A. Thus during both the downward and upward motion of the board B, a current of compressed air is driven through the nozzle A.

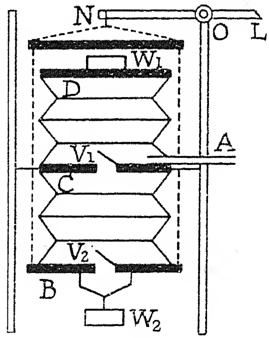


FIG. 104.
DOUBLE-ACTING BELLOWS.

FANS

Fans are devices for setting air in motion. A centrifugal fan is shown in Fig. 105. W is the impeller wheel which is rotated by an electric motor inside the cast-iron casing C. The air is seized by the blades of the impeller and thrown off tangentially from the tips of the blades. In this way a current of air is driven through the outlet O. Air is drawn through the eye E in the side of the casing, to neutralise the vacuum which tends to be produced.

Fans are extensively used in many modern appliances such as vacuum cleaners, ventilators, etc. They are also used for driving strong currents of air through the kilns

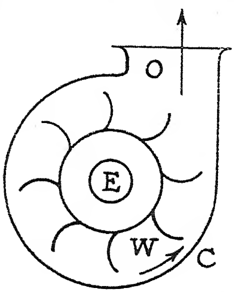


FIG. 105.
CENTRIFUGAL FAN.

in the seasoning of timber and, in conjunction with the bellows, for driving strong currents of air into forge fires.

The Vacuum Cleaner

The modern vacuum cleaner (Fig. 106) consists essentially of a fan A which is rotated by an electric motor M, connected by leads to a plug in the wall. When the current is switched on the fan rotates, throwing the air off the tips of the blades by centrifugal action and producing a partial vacuum in the chamber B. Air and grit which enter at C are drawn through the opening D and driven along the pipe E into the straining bag F, which is situated in the cylinder G. The grit remains in the bag and the air escapes through the meshes into the atmosphere.

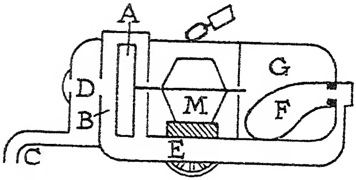


Fig. 106.

VACUUM CLEANER.

The Water Barometer

Example. The atmosphere supports a vertical column of mercury 30 ins. long. What length of water column will the atmosphere support?

R.D. of mercury = 13·6.

Let w = wt. of 1 cub. in. of water in lbs.

and h = length of water column in inches.

Pressure due to mercury column = $30 \times w \times 13{\cdot}6$ lbs. per sq. in.
Also pressure due to water column = hw lbs. per sq. in.

$$\therefore hw = 30 \times w \times 13{\cdot}6$$
$$\therefore h = 30 \times 13{\cdot}6$$
$$= 408 \text{ inches.}$$

Thus the height of the water barometer is approximately 408 inches or 34 feet.

The Siphon

The siphon is a simple instrument which depends on the atmospheric pressure for its action. In Fig. 107, Z is a vessel containing a quantity of liquid and ABCD is a glass tube bent twice at right angles. This tube

is completely filled by suction, with the liquid in Z. If the end D of the tube is below the level PQ the liquid will flow out of the vessel, provided no air bubbles are present in the tube. The theory of the siphon is as follows:—

Since the pressure at a depth in a liquid is proportional to the depth, the pressure at all points of the liquid, in the same horizontal plane, is the same. Thus:

Pressure within the tube at Y = Pressure in the tube at X
= Atmospheric pressure on the surface PQ.

Thus the pressure inside the tube at D is greater than atmospheric pressure, by the pressure due to the column of liquid YD. Thus the downward pressure of the liquid in the tube at D is greater than the upward pressure of the atmosphere and the liquid runs out of the tube.

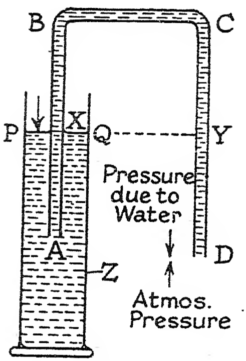


FIG. 107.

SIPHON.

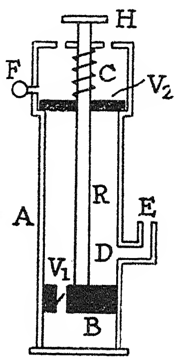


FIG. 108.

GERYK VACUUM PUMP.

THE GERYK VACUUM PUMP

A modern form of mechanical vacuum pump is the Geryk pump shown in Fig. 108. A is a metal cylinder in which a piston B is worked by a rod R, attached to a handle H. A valve V_1, opening upwards, is situated in the piston and another valve V_2, in the form of a movable circular plate, closes the cylinder. This plate, through which the piston rod passes freely, is held down by a helical spring C. The vessel to be exhausted is attached to the suction tube E which leads from the air port D. A layer of oil rests on the plate V_2 and the piston is smeared

with oil on its upper surface. A screw plug F enables oil to be added or withdrawn as required.

Suppose the piston is in contact with the plate V_2. In this case the oil prevents the presence of air between the piston and the plate. As the piston is forced downwards, a perfect vacuum is formed between the valve V_2 and the piston, until a stage is reached when the pressure of the air below the piston is sufficient to open the valve V_1. When the piston passes the air port D, the air from the vessel, attached to the tube E, distributes itself uniformly throughout the vessel and the cylinder.

On the upstroke V_1 closes and, when the piston is above the air port D, the air is compressed until the pressure is sufficient to raise the plate V_2. In this manner air escapes through the oil into the atmosphere. Thus on each successive down and up stroke, air is withdrawn from the vessel, until the required degree of exhaustion is reached.

The Lift Pump

Fig. 109 shows a model of a lift pump which can be constructed out of glass tubing, etc. AB is the barrel which tapers at the lower end and terminates in the pipe BC. The piston P, shown also in detail, consists of a small glass reel to which a U shaped piece of glass rod is fused. The handle H, also made of glass rod, is fused to this U shaped piece. The glass reel is wound with several turns of thin string which causes the piston to fit tightly in the tube. A glass bead D, which acts as a valve, rests on the upper end of the opening in the reel. Another glass bead E rests in the tapered portion of the tube and serves as a second valve. The model rests with the end of the pipe C immersed in water, contained in a trough.

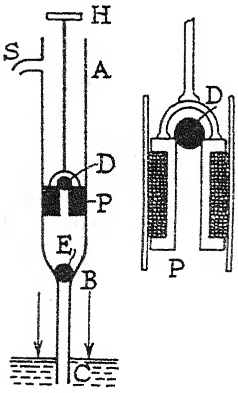


FIG. 109.
MODEL OF A LIFT PUMP.

To explain the action of the pump, suppose the piston P to be at the bottom of its stroke near the valve E. As the piston is raised the air below it expands and the pressure consequently decreases. The pressure on the lower side of the valve E is thus greater than that on the upper side and the valve E is raised. Air leaves the pipe BC and enters the barrel AB. Consequently the air in the pipe BC is at a lower pressure than the air outside. Thus water rises in the pipe CB and continues to rise until the piston reaches the upper end of its stroke. As the

piston descends, the air in the barrel below the piston is compressed, the valve E closes and the valve D opens, allowing air and water to escape from the lower to the upper side of the piston. On raising the piston again the process is repeated, until all the air is withdrawn from the barrel and the water rises to such a height that it can flow through the spout S.

We have already seen that the height of the water barometer is approximately 34 feet. Thus, if all the air is withdrawn from the barrel and the pipe, the water cannot rise more than 34 feet. In practice, however, the height to which water can be raised by a lift pump is only about 28 feet. This is due mainly to leakage of air between the piston and the barrel.

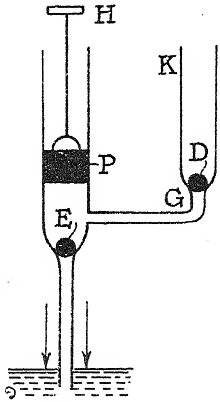


FIG. 110.
MODEL OF A FORCE PUMP.

THE FORCE PUMP

Fig. 110 represents a model of a force pump. This differs from the lift pump in the following particulars. The piston P has no valve and a side tube passes out from the lower end of the barrel, terminating in a long vertical tube GK. The glass bead D represents a second valve.

Water is raised above the level of the horizontal tube, as in the lift pump. Then, as the piston descends, the valve E closes and water is forced past the valve D. As the piston again rises, the valve D prevents the water above it from running back to the barrel and more water passes E. As the piston descends, water is again forced past D and so on. In an actual force pump, water can be forced to a height considerably greater than 34 feet, the height depending on the power applied to the piston.

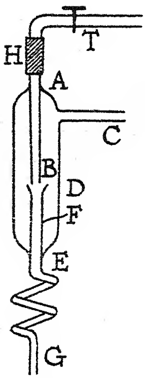


FIG. 111.
FILTER PUMP.

THE FILTER PUMP

The filter pump shown in Fig. 111 is a simple form of air pump used for exhausting a vessel. The pump consists of a bulb D, into which is fused a glass tube AB, with a very fine orifice at B. FE is a straight tube, fused into the bulb and ending in a spiral G. The tube AB is connected by stout rubber tubing H to a water tap T. As the water issues from the

orifice at B, air particles are carried in the waterstream through the tube FE. In time, the bulb D and the vessel connected to the side tube C are nearly exhausted.

The Rotary Oil Pump

A modern form of exhaust pump which produces a moderately high vacuum is the rotary oil pump, the essential features of which are shown in Fig. 112. A cylinder A, mounted eccentrically in a cylindrical steel casing B, is rotated by an electric motor. Two hardened steel plates C and D, with rounded edges and moving in slots, are kept in close contact with the walls of the casing B by centrifugal action (see Ch. V).

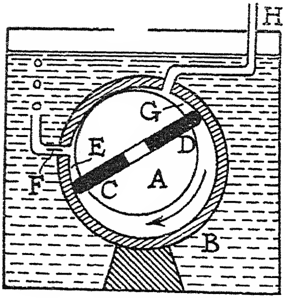


Fig. 112.

ROTARY OIL PUMP.

The cylinder A is rotated in a clockwise direction and the air in the space E is compressed. This compressed air is forced through the valve F and escapes through the oil which surrounds the casing into the atmosphere. The partial vacuum which is produced in the space G is neutralised by the air drawn through the tube H, which is connected to the vessel to be exhausted. When the plates C and D interchange positions, more air is swept through the valve and so the process continues. The oil in the tank surrounding the casing acts as a lubricator for the spindle of the rotating cylinder.

The Diffusion Pump

When a very high vacuum is required a diffusion pump is used in conjunction with a rotary oil pump. The essential features of the diffusion pump are shown in Fig. 113. Mercury is boiled at a low pressure in the vessel A. The mercury vapour produced passes up the tube B, which is lagged with asbestos to prevent heat losses to the surroundings. The mercury vapour is thus prevented from condens-

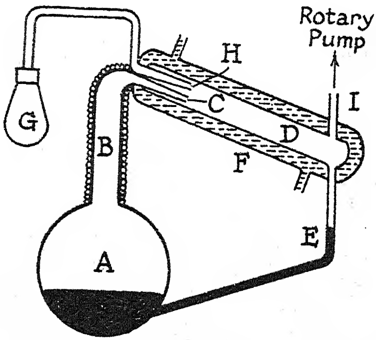


Fig. 113.

DIFFUSION PUMP.

ing in the upper part of the tube. The mercury vapour then issues through the opening C into the vessel D, where it condenses and passes back to the vessel A by way of the tube E, the necessary cooling being produced by the condenser F. Air particles from the bulb G diffuse through the aperture H and are carried by the vapour stream and directed towards the exit tube I to which the rotary oil pump is attached. Thus there is a progressive reduction of pressure in the bulb G until it becomes exhausted.

The size of the diffusion aperture H is of great importance and must be of the correct order if diffusion is to take place. Again the pump cannot operate by itself but must be attached to a "backing" pump, such as a rotary oil pump, so that an initial low pressure is produced in the vessel D.

The diffusion pump, in conjunction with a "backing" pump, is used in modern practice for exhausting electric light bulbs, wireless valves, X-ray tubes, etc.

The Petrol Pump

The essential features of a modern petrol pump are shown in Fig. 114. In this pump, which is known as the Theo Multiple Pump, air is evacuated from the container B through the suction pipe A, either by a rotary oil pump applied to G or a hand pump applied to H, the change-over cock F being adjusted accordingly.

The spirit in the underground tank is under atmospheric pressure and, owing to the vacuum formed, rises up the pipe M, through the cock E, up the supply pipe N and finally up the sliding measure tube C into the container B. The exact measure is determined by the height of the sliding measure tube C, set according to the volume of petrol required. When the required measure is obtained, an automatic stop valve D shuts off the supply of petrol. The vacuum of the container B is automatically broken when the discharge cock K is opened and the petrol is delivered to the car through the pipe L.

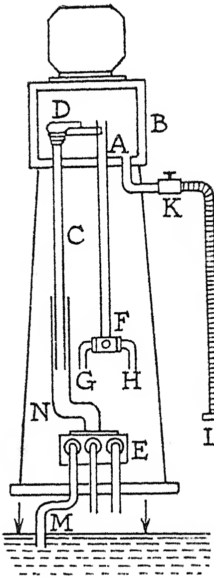


Fig. 114.

PETROL PUMP.

The cock E is a multiple six-way cock which

communicates with any one of the underground tanks, each of which contains a different grade of petrol.

The Compression Pump

The mechanism of a compression pump is similar to that of an exhaust pump, except that the direction of the valves is reversed. In Fig. 115, the essential features of a compression pump are shown. A is the cylinder in which the piston B is worked by the handle attached to the piston rod C. On the downstroke, when the piston has passed the air port D, the valve V_1 closes and the air below the piston is compressed. When the pressure attains a definite value, air is forced through the valve V_2, through the open cock E and into the compressed air receiver F. On the upstroke, a partial vacuum is produced in the cylinder and the valve V_1 opens, admitting more air into the cylinder. The valve V_2 also closes, preventing the air from passing back from the compressed air receiver into the cylinder. This process is repeated, until the gauge G indicates the safe pressure which the receiver can withstand. The cock E is then closed and the compressed air is ready to be withdrawn through the cock H for the purpose required.

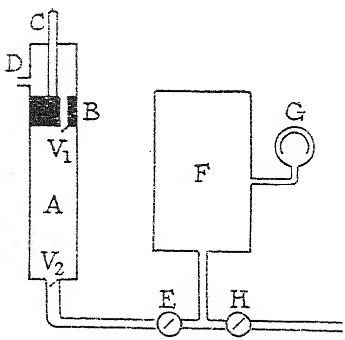


Fig. 115.
COMPRESSION PUMP.

Compressed air is utilised in many modern machines such as coal cutting machines, riveting hammers, drills and locomotive brakes.

Exercises X

1. How can atmospheric pressure be measured ? Explain the meaning of the expression "a pressure of ten atmospheres." Describe the construction of a piece of apparatus by means of which you could measure the pressure of air in a glass flask which has been partly exhausted by means of an air pump.

(C. G. L. I.; Hand. S.)

2. An air compressing machine takes in 100 cub. ft. of air from the atmosphere, and compresses it to a pressure of 100 lbs. per sq. inch, in excess of atmospheric pressure. Assuming the temperature to be

constant, calculate the volume of the compressed air. The pressure of the atmosphere = 14·7 lbs. per sq. inch.

3. Explain, with the aid of a sketch, the working of a pump by which water could be raised through a vertical height of 40 feet.

(C. G. L. I.; Hand. S., part Question.)

4. A single acting lift pump is worked by the hand at 20 strokes per minute. The diameter of the piston is 2″ and the length of the stroke 5″. Calculate the volume of water lifted per hour, if the efficiency of the pump is 80 per cent.

5. (*a*) Describe an experiment to show that air exerts a pressure in all directions.

(*b*) Explain the action of the double-acting forge bellows.

(C. G. L. I.; Hand. S.)

6. Gas enclosed in a cylinder has a volume of 12 cubic feet at a pressure of 90 lbs. per sq. inch. It is allowed to expand without change of temperature until its volume is 28·8 cubic feet. What is the pressure now ?

State the law upon which your calculation is based.

(U. L. C. I.; P. S. T.)

7. What is Boyle's Law ? Describe in detail how you would show by experiment that air at ordinary temperatures obeys the law.

(U. L. C. I.; P. S. T.)

8. Describe the construction and use of (*a*) an air pump, (*b*) a tyre inflator.

(C. G. L. I.; Hand. S.)

CHAPTER XI

HEAT (A)

Expansion

All substances, whether solid, liquid or gas, with few exceptions, increase in size or expand when heated and decrease in size or contract when cooled. A few qualitative experiments will illustrate this expansion.

Experiment XXIV

To show the expansion of a solid due to heat

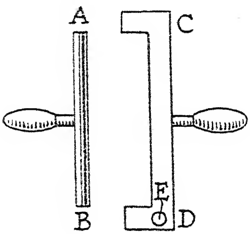


Fig. 116.
EXPANSION OF A ROD.

In this experiment, the apparatus shown in Fig. 116 is used. AB is an iron rod and CD an iron frame, each mounted on a wooden handle. At air temperature, the rod exactly fits into the frame, and the end of the rod fits into the circular hole E. Verify this by trial.

Now heat the rod in a bunsen flame and again try to insert the rod in the frame. Also try to insert the end of the rod in the circular hole.

In neither case is this possible. The experiment thus shows that a solid expands in all directions when heated.

Experiment XXV

To show that a liquid increases in volume when heated

Take a flask, provided with a tight fitting rubber stopper, through which a glass tube passes (Fig. 117). Fill the flask and tube up to the mark A with coloured water, taking care that there are no air spaces. Support the flask by a stand and allow it to rest on a tripod, fitted with wire gauze. Heat the flask by means of a bunsen burner, when the water level will fall from A to B and then rise to C. The glass vessel, receiving the heat before the water, increases in volume and consequently the water level falls to B. However, when the water also becomes hot its level rises to C.

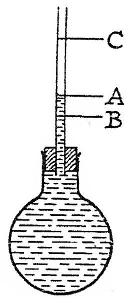


Fig. 117.
EXPANSION OF A LIQUID.

Experiment XXVI

To show that air increases in volume when heated

Take an empty flask, provided with a tight fitting stopper, through which passes a piece of glass tubing, bent four times at right angles (Fig. 118). Remove the stopper and place coloured water in the tube. Now replace the stopper and apply heat to the flask (the heat from the hands is sufficient). The water level at A descends to A_1, while that at B ascends to B_1.

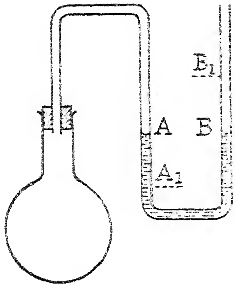


Fig. 118.
EXPANSION OF AIR.

Heat and Temperature

Just as water flows from a high level to a low level, so heat flows from a hot body to a cold body, when these bodies are in contact with each other. The hot body is said to have a higher temperature than the cold body.

Thus heat and temperature are analogous to quantity of water and water level respectively. Quantity of heat is measured in heat units, an account of which will be given later, whereas temperature is measured by means of an instrument known as a thermometer.

The Thermometer

A thermometer in everyday use is the mercury-in-glass thermometer. This thermometer consists of a capillary tube of narrow bore with a bulb at one end and closed at the other end. The bulb and a portion of the tube contain mercury. The stem has two fixed points marked upon it, the lower and upper fixed points representing the Freezing Point and Boiling Point of pure water respectively. The space between the fixed points is divided into a number of equal divisions to represent temperatures.

To mark the fixed points on an ungraduated thermometer, the bulb is placed in crushed ice, contained in a funnel, as shown in Fig. 119, and allowed to remain for a few minutes. The thermometer is then raised a little, in order to mark the stem at the mercury surface. This is done by means of a file and the mark represents the freezing point.

To mark the upper fixed point, the thermometer is placed in an hypsometer (Fig. 120), so that the bulb is surrounded by the steam from boiling water. The stem, at the mercury surface, is again marked

with a file and this mark represents the upper fixed point. Since the presence of dissolved salt in solution raises the boiling point it is

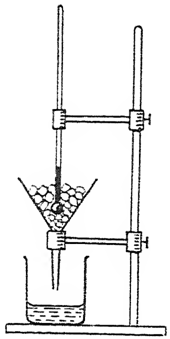


FIG. 119.

APPARATUS FOR MARKING THE FREEZING POINT OF A THERMOMETER.

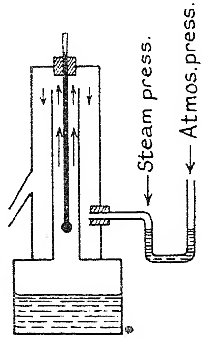


FIG. 120.

HYPSOMETER.

essential to place the bulb in the steam, as the temperature of the steam is always the same so long as the atmospheric pressure does not vary.

The ungraduated thermometer can now be calibrated by placing it alongside a calibrated thermometer in a vessel containing water. Starting with ice-cold water and gradually increasing the temperature, the ungraduated thermometer can be marked in degrees to correspond to the various temperatures, indicated by the calibrated thermometer.

SCALES OF TEMPERATURE

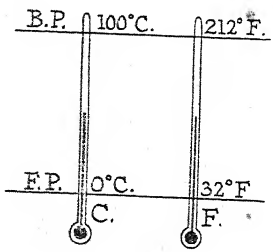


FIG. 121.

SCALES OF TEMPERATURE.

The two chief scales used in this country are the Centigrade and the Fahrenheit scales (Fig. 121). On the Centigrade scale, the freezing point (F.P.) of water is 0° Centigrade (0°C) and the boiling point (B.P.), 100° Centigrade (100°C). On the Fahrenheit scale the freezing point is 32° Fahrenheit (32°F) and the boiling point 212° Fahrenheit (212°F). Thus: 180 Fahrenheit divisions = 100 Centigrade divisions or 1 Fahrenheit division = $\frac{5}{9}$ Centigrade division.

Let F and C be the readings representing the same temperature on the Fahrenheit and Centigrade scales respectively. Then the number of divisions above F.P. of the Fahrenheit reading is F—32, and the number of divisions above the F.P. of the Centigrade reading is C.

$$\therefore \frac{F-32}{C} = \frac{9}{5}$$

$$\text{or } F = \frac{9}{5}C + 32$$

Example. Convert 10°C into the Fahrenheit scale.

$$\text{In the relation } F = \frac{9}{5}C + 32, \text{ put } C = 10$$

$$\therefore F = \frac{9}{5} \times 10 + 32 = 50°F.$$

Example. Convert 68°F into the Centigrade scale.

$$\text{We have:— } F = \frac{9}{5}C + 32$$

$$\text{Substitute } F = 68$$

$$\therefore 68 = \frac{9}{5}C + 32$$

$$\therefore C = \frac{5}{9}(68 - 32) = 20°C.$$

Liquids used in Thermometers

For ordinary ranges of temperature there are two liquids in common use—mercury and alcohol. A comparison of their properties gives information regarding their relative merits as thermometric liquids. Since mercury boils at 357°C and freezes at —39°C, it is useful for ordinary ranges of temperature. On the other hand, alcohol boils at 78°C and freezes at —119°C, so that alcohol is useful for low-temperature thermometers.

As a thermometric liquid, mercury possesses an advantage over alcohol, in so far that it can be seen through glass, whereas alcohol is colourless. In some thermometers colouring matter is placed in the alcohol to render it visible. Again, alcohol is more sensitive as regards expansion than mercury, that is, 1 c.c. of alcohol expands more than 1 c.c. of mercury for the same increase in temperature.

Maximum and Minimum Thermometers

A maximum thermometer indicates the maximum temperature attained during a certain period, whereas a minimum thermometer indicates the minimum temperature reached.

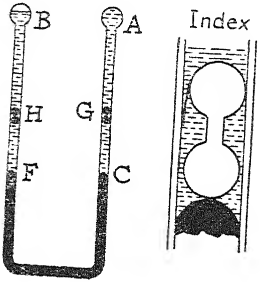


Fig. 122.
MAXIMUM AND MINIMUM THERMOMETER.

Fig. 122 represents Six's maximum and minimum thermometer, which is a combined instrument for registering the maximum and minimum temperatures.

A and B are two bulbs connected by a U tube, marked in degrees. The lower portion of the U tube contains mercury and the bulb A and the portion AC of the tube contain alcohol. Alcohol also occupies the portion FB, a space being left in B to allow for expansion. G and H are steel indices fitted with springs. As the temperature falls, the mercury meniscus C pushes the index G up the tube. As the temperature rises, however, the alcohol flows past the index G, which is kept in position by the spring attached to it and the index H is pushed up the tube. Thus the lower end of the index G registers the lowest temperature reached, and the lower end of H registers the highest temperature. At the beginning of the period the indices can be moved into position by means of a small magnet.

High Temperature Measurement—Pyrometers

Seger's Fusible Cones

The softening which accompanies the melting of clay is sometimes utilised for obtaining an approximate value of the temperature attained by a brick kiln. A set of thin cones is shown in Fig. 123(*a*). The cones consist of clay mixtures of known melting point (see p. 128) and these bend over as the temperature of softening is reached. The temperature of the brick kiln may then be gauged by noting which cones remain upright and which bend over.

Pyrometers

When high temperatures such as the melting point of a metal or the temperature of a furnace are required, pyrometers are used.

Fig. 123(*b*) shows two wires, one iron and the other copper, fused

together at A. The other ends of the wires are connected to the terminals of a galvanometer G (see Ch. XVII). When the junction A is heated an electric current flows in the wires and this current produces a deflection of the galvanometer needle.

This principle is utilised in the thermocouple pyrometer, in which the two wires are made of copper and eureka or, better still, platinum and an alloy of platinum and rhodium. The thermocouple is calibrated by placing the junction, protected by some covering such as a porcelain casing, in steam at 100°C and in a furnace at known high temperatures, the galvanometer reading being noted for each temperature. The

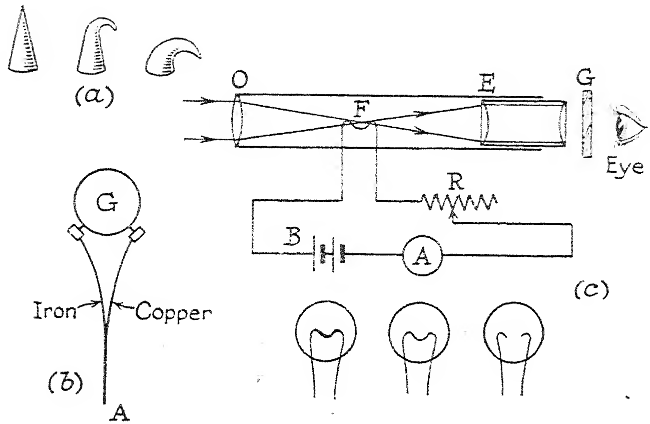


FIG. 123.
(*a*) FUSIBLE CONES, (*b*) THERMOCOUPLE PYROMETER, (*c*) OPTICAL PYROMETER.

galvanometer scale is marked to read these temperatures and the instrument can then be used for measuring unknown high temperatures.

Another instrument, used for measuring the high temperatures of incandescent bodies, is the optical or disappearing filament pyrometer. The essential features of this instrument are shown in Fig. 123(*c*). A filament F, of tungsten wire, is in series with a battery B, an ammeter A and a variable resistance R (see Ch. XVI). The filament is inserted, in the case of a telescope, between the objective O and the eyepiece E. (See textbook on Light.) The telescope is held at a specified distance from the furnace whose temperature is required, the objective O is turned towards the furnace and gives an image of it at the filament. The eyepiece E is then focused on the filament and a sheet of red glass G is placed between the eye and the eyepiece. The current in the

filament is varied until the filament disappears against the red background of the furnace. If the current is too small the filament appears black, and if too large it appears white hot. The ammeter reading is noted when the filament disappears.

The instrument is calibrated by viewing a furnace at known high temperatures and marking these known temperatures on the ammeter scale. The calibrated pyrometer may then be used for the determination of the unknown high temperatures of incandescent bodies.

Coefficient of Linear Expansion of a Solid

Although a solid expands in all directions when heated, we are often concerned with the expansion in one direction only, as in the case of rods, pipes, etc. This is known as linear expansion. The linear expansion or the increase in length of a solid depends on the length, the increase in temperature and the material of which it is composed. Thus it is incorrect to say that brass expands more than iron, unless we specify equal lengths and the same temperature rise. This leads us to the conception of coefficient of linear expansion, which is the increase in length, per unit length, per unit rise of temperature.

Example. A length of iron piping at 60°F has steam at 212°F passed through it. If the piping is 80 feet long, and the coefficient of linear expansion of iron is 0·0000067 per °F, find the expansion of the piping.

Expansion of 1 ft. for 1°F rise = 0·0000067 ft.
" " 80 ft. for 1°F rise = 80 × 0·0000067 ft.
" " 80 ft. for 152°F rise = 80 × 0·0000067 × 152 ft.
= 0·08 ft.
= 0·96 ins.

Thus: Expansion = Initial length × Coefficient × Temperature increase.

Example. A steel crank has a circular hole which is 2·99 inches in diameter at 15°C. To what temperature must the crank be raised so that it will fit on a flywheel shaft, 3 inches in diameter, allowing 0·01 inch clearance all round? The coefficient of linear expansion of steel is 0·000012 per deg. C.

Expansion = 3·02 ins. — 2·99 ins.
= 0·03 ins.

But Expansion = Initial diameter × coefficient × temperature increase

$$\therefore 0{\cdot}03 = 2{\cdot}99 \times 0{\cdot}000012 \times t$$

where t = the temperature increase.

$$\therefore t = \frac{0{\cdot}03}{2{\cdot}99 \times 0{\cdot}000012}$$

$$= 833 \text{ degrees.}$$

Hence required temperature $= 833°C + 15°C.$

$= 848°C.$

Practical Applications

Since solids expand when heated, allowance for this expansion has to be made in many constructional processes. In the case of railway lines, spaces have to be left between the ends of the lines to allow for

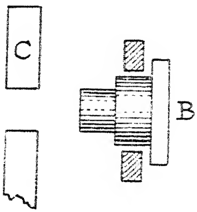


Fig. 124.

CRANK PIN OF AN ENGINE.

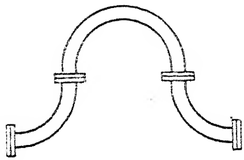


Fig. 125.

LOOPS IN HOT WATER PIPES.

expansion in summer. For the same reason, spaces are left to allow for expansion of girders in buildings and in bridges.

When a solid is cooled, after being heated to a high temperature, and contraction is prevented, the solid exerts a tremendous force. A practical application of this fact is shown in Fig. 124, where C represents the crank arm of an engine and B, the crank pin. The hole in the crank arm is only large enough when hot to admit the pin. When the crank arm cools, the pin is thereby gripped very tightly.

This method of expansion fitting has one disadvantage. In the case of some metals, e.g., steel and work hardened metals, the external member has its properties altered at high temperatures. A method of overcoming this disadvantage is to make the internal member slightly greater than the external member at ordinary temperatures and to cool the internal member, e.g., the crank pin in Fig. 124, to the temperature of liquid air, viz., $-182°C$. When the pin is inserted it expands and a tight fit is obtained.

In the case of the pipes used in a steam engine, expansion will cause them to buckle if provision is not made. To prevent this buckling, bends or loops are arranged in the pipes and these take up the expansion when steam passes through them (Fig. 125). Hot water pipes are also provided with bends, or are fastened together by telescopic points, to allow for expansion when hot water passes through them.

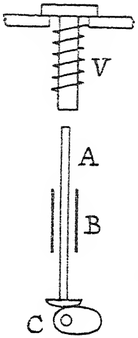


FIG. 126.
TAPPET AND MUSHROOM VALVE IN PETROL ENGINE.

Allowance is also made for the expansion of the tappet due to heat in the petrol engine, in which a space is left between the tappet and the mushroom valve (Fig. 126). The tappet A, sliding in the tappet guide B, rests on the cam C whose shaft is geared to the crankshaft. These parts are fitted at a temperature considerably below the temperature of the hot engine and expand when the engine is running. In this case, if clearance is not left the valve V would be open for all positions of the cam. The space, however, allows for expansion and correct valve closing is obtained.

In moulding, castings have to be made to specified dimensions and the mould is made slightly greater so that on contraction the casting acquires these dimensions. Pattern makers' rules are therefore constructed with their divisions slightly longer than the true length in a ratio, depending on the coefficient of expansion of the metal and the temperature from which it cools.

HEAT UNITS

Quantity of heat may be measured by its heating effect on a quantity of water. Thus the quantity of heat required to raise the temperature of 20 grams of water from 10°C to 20°C is double the quantity of heat required to raise the temperature of 10 grams of water from 10°C to 20°C. Also the quantity of heat required to raise the temperature of 20 grams of water from 10°C to 30°C is double the quantity of heat required to raise the temperature of 20 grams of water from 10°C to 20°C.

Quantity of heat is measured in heat units, of which the simplest is the calorie.

The Calorie is the quantity of heat which must be imparted to one gram of water to raise its temperature by 1°C.

Other units of heat, used particularly in engineering, are the British Thermal Unit and the Pound Calorie.

The British Thermal Unit (B.Th.U.) is the quantity of heat which must be imparted to one pound of water to raise its temperature by 1°F.

The Pound Calorie or Centigrade Heat Unit (C.H.U.) is the quantity of heat which must be imparted to one pound of water to raise its temperature by 1°C.

Thus 1 C.H.U. = 1 lb. of water through 1°C.

and 1 B.Th.U. = 1 lb. of water through 1°F.

∴ 1 B.Th.U. = $\frac{5}{9}$ C.H.U., since one Fahrenheit degree is equal to $\frac{5}{9}$ of a Centigrade degree.

Example. How much heat is lost by 400 grams of water in cooling from 100°C to 15°C?

Heat lost by 1 gram for 1°C fall = 1 cal.

Heat lost by 400 grams for 1°C fall = 400 cals.

Heat lost by 400 grams for 85°C fall = 400 × 85 cals.

= 34,000 cals.

Example. Water circulates through a condenser at the steady rate of 200 lbs. per minute. The inlet and outlet temperatures are 15°C and 25°C respectively. How much heat is taken from the condenser by the circulating water per hour?

Heat gained by circulating water per min. = 200 × (25 − 15) C.H.U.s

= 2,000 C.H.U.s.

Heat gained by circulating water per hour = 2,000 × 60 C.H.U.s

= 120,000 C.H.U.s.

From the preceding examples it can be seen that:—

Heat gained or lost by water = Weight of water × Temperature change.

The Therm. A much larger heat unit is the therm, which is the unit by which we pay for gas supply. A therm is equal to 100,000 British Thermal Units.

Calorific Value

Different fuels such as coal, paraffin, gas, etc., have different heating values. This heating value or calorific value, as it is generally called, is the quantity of heat given out by the complete combustion of 1 lb. of fuel, in the case of solid and liquid fuels, or the quantity of heat given out by the complete combustion of 1 cubic foot of gas, in the case of a gaseous fuel. Gas companies and corporations manufacture gas of a definite calorific value, e.g., 480 B.Th.U. per cubic foot.

Example. The reading of a gas meter at the beginning of a quarter is 352 units and at the end of the quarter 440 units. Find the amount of heat given out by the combustion of the gas. 1 unit = 100 cub. ft.

Number of units	= 440 − 352
	= 88.
Volume of gas consumed	= 88 × 100 cub. ft.
	= 8,800 cub. ft.
Heat given out	= 8,800 × 480 B.Th.U.s
	= 4,224,000 B.Th.U.s
	= 42·24 Therms.

Capacity for Heat

Experiment XXVII

Take two exactly similar test tubes and weigh out 10 grams of water into one and 10 grams of paraffin into the other. Place the bulb of a centigrade thermometer in each liquid and allow the tubes to stand in a beaker, containing hot water at 70°C, until the temperatures of the paraffin and the water are the same. Now pour the paraffin into a test tube containing 10 grams of cold water and pour the hot water into a similar test tube also containing 10 grams of cold water. After shaking, note the temperature of the mixture in each case.

It will be found that the temperature of the mixture of the two quantities of water is greater than that of the mixture of paraffin and water. This shows that the water gives out more heat than an equal weight of paraffin. Thus water has a greater heat capacity than paraffin.

Specific Heat

We have seen that water has a greater heat capacity than an equal weight of paraffin, that is, one gram of water requires more heat to raise its temperature through 1°C than one gram of paraffin. This leads us to the conception of specific heat, which may be defined as follows:—

The Specific Heat of a Substance is the quantity of heat required to raise the temperature of one gram of a substance through 1°C, compared with the quantity of heat required to raise the temperature of one gram of water through 1°C.

i.e., $$\text{Specific heat of a substance} = \frac{\text{Heat to raise 1 gram of substance 1°C}}{\text{1 Calorie}}$$

If measured in British Thermal Units, we have:—

$$\text{Specific heat of a substance} = \frac{\text{Heat to raise 1 lb. of substance 1°F}}{\text{1 B.Th.U.}}$$

It is evident from the above that the value of the specific heat of a substance is a ratio which is the same whatever system of units is used to define the heat unit. Thus the specific heat of iron is 0·12 calories per gram per degree Centigrade, 0·12 British Thermal Unit per pound per degree Fahrenheit or 0·12 Centigrade Heat Unit per pound per degree Centigrade.

Example. Find the quantity of heat that must be imparted to 100 lbs. of iron to raise its temperature from 60°F to 200°F. Specific heat of iron = 0·12 B.Th.U. per lb. per deg. F.

Heat gained by 1 lb. of water for 1°F = 1 B.Th.U.
,, ,, ,, 1 lb. of iron for 1°F = 0·12 B.Th.U.
,, ,, ,, 100 lbs. of iron for 1°F = 100 × 0·12 B.Th.U.s.
,, ,, ,, 100 lbs. of iron for 140°F = 100 × 0·12 × 140 B.Th.U.s
= 1,680 B.Th.U.s.

From the preceding example, it can be seen that during a transference of heat the heat gained or lost by a substance is given by:—
Heat gained or lost = Weight of substance × Sp. Ht. × Temperature change.

Thermal Capacity

The thermal capacity of a substance is the quantity of heat which must be given to the substance to raise its temperature by one degree.

$$\text{i.e., Thermal capacity of substance} = \frac{\text{Weight of substance} \times \text{Sp. ht.} \times \text{Temp. rise}}{\text{Temperature rise}}$$
$$= \text{Weight of substance} \times \text{Sp. ht.}$$

Thus the thermal capacity of 100 grams of iron (Sp. ht. = 0·12) is 100 × 0·12 calories per deg. C.

Water Equivalent

The water equivalent of a substance is the weight of water which gains the same quantity of heat as the substance for the same temperature rise.

Thus 200 lbs. of iron (Sp. ht. = 0·12) gains the same quantity of heat as 200 × 0·12 lbs. of water for the same temperature rise. Hence the water equivalent of 200 lbs. of iron is 200 × 0·12 lbs. of water, i.e., 24 lbs. of water.

Method of Mixtures

When a quantity of hot water at a temperature t_1 is mixed with a quantity of cold water at a temperature t_2, the mixture attains some intermediate temperature t_3. The value of the temperature t_3 depends on the relative quantities of hot and cold water. Also the quantity of heat lost by the hot water is equal to the quantity of heat gained by the cold water, so long as no heat is lost to the surroundings.

Example. What weight of boiling water at 212°F must be mixed with 200 lbs. of water at 60°F so that the temperature of the mixture is 80°F ?

$$\text{Heat lost by hot water} = \text{Heat gained by cold water}$$

$$\text{i.e., } w \times (212 - 80) \text{ B.Th.U.s} = 200 \times (80 - 60) \text{ B.Th.U.s.}$$

where w = the weight of hot water added.

$$\therefore \quad 132w = 4{,}000$$

$$\therefore \quad w = 30{\cdot}3 \text{ lbs.}$$

Example. In an experiment to find the specific heat of aluminium, a piece of aluminium, weighing 0·5 lb., at a temperature of 100°C, is immersed in a vessel of thermal capacity 0·5 C.H.U. per deg. C and containing 1·2 lbs. of water at 10°C. If the steady temperature of the mixture is 15°C, find the specific heat of the aluminium. Assume no heat losses to the surroundings.

$$\text{Heat lost by aluminium} = \text{Heat gained by water} + \text{Heat gained by vessel}$$

$$0{\cdot}5 \times x \times (100 - 15) \text{ C.H.U.s} = 1{\cdot}2 \times (15 - 10) \text{ C.H.U.s} + 0{\cdot}5 \times (15 - 10) \text{ C.H.U.s.}$$

where x = Sp. ht. of aluminium.

$$\therefore \quad 42{\cdot}5x = 6 + 2{\cdot}5$$

$$\therefore \quad x = \frac{8{\cdot}5}{42{\cdot}5}$$

$$= {\cdot}20 \text{ C.H.U. per lb. per deg. C.}$$

The Thermal Characteristics of Water

Liquids generally expand with increase of temperature. But when water is heated from 0°C to 4°C it contracts and then expands from 4°C upwards. This anomalous expansion of water is shown graphically in Fig. 127, where the ordinates represent the volume of one gram of water and the abscissæ the temperature. The line CD represents the con-

traction from 0°C to 4°C while DE represents the expansion from 4°C upwards. The ordinate at G, viz., GD, represents the volume of one gram of water at 4°C, which is one cub. cm., and, since this volume is a minimum, water has its maximum density at 4°C.

It is a well known fact that ice floats in water and we have already seen (Ch. IX) that a floating solid has a smaller density than the liquid in which it floats. The density of water is 1 gram per c.c. whereas the density of ice is 0·91 gram per c.c. or the volume of 1 gram of ice is $\frac{1}{0{\cdot}91}$ c.c.s, i.e., 1·097 c.c.s. This is shown in Fig. 127 by the line OB, while CB represents the sudden expansion of water on freezing. The contraction of ice on cooling below 0°C is shown by the line BA.

Finally, water is the substance used in defining the heat unit and its specific heat is the greatest for all substances, viz., one calorie per gram per degree Centigrade.

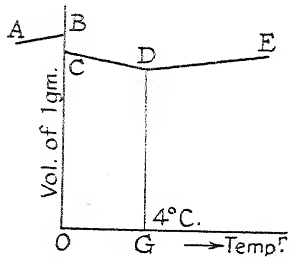


FIG. 127.
ANOMALOUS EXPANSION OF WATER.

These characteristics of water play a very great part in nature. Let us consider the case of its anomalous expansion. Suppose the air above a sheet of water is at a temperature of 15°C. As the air cools, the top layer of water also cools, becomes more dense and descends to a lower level. Warm water rises to the surface and this also cools. Thus by degrees the whole mass of water cools to 4°C. Any further cooling of the surface layer causes the water to become less dense and this layer cannot sink. Ultimately the surface layer freezes but the mass of water underneath remains at 4°C and cannot freeze. Ice, being less dense than water, remains on the surface and gradually increases in thickness.

The high specific heat of water causes the temperature changes of large masses of water to be very slow. This is one of the factors which cause islands to have temperate climates as distinct from the extreme climates of large land masses. In the case of islands the water acts as a kind of blanket, by helping to keep the land warm in winter and cool in summer.

Melting Point and Boiling Point

Suppose heat is supplied at a constant rate to a mixture of ice and water at 0°C, and the mixture is well stirred. If the temperature is

read at intervals of a minute and the temperatures are plotted against the time in minutes, the graph ABCD (Fig. 128) is obtained. The portion AB represents the change of state from ice to water. So long as any ice is present the temperature remains at 0°C, and the point B represents the instant when all the ice has melted. Again, BC represents the rise of temperature of the water with time and the heat supplied during this operation is known as sensible heat. The point C represents the instant when boiling begins and the horizontal portion CD shows that the temperature remains constant at boiling point, that is, during the change of state from water to steam.

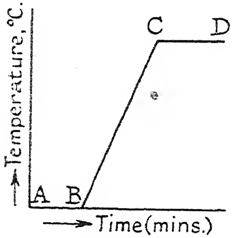


FIG. 128.
MELTING AND BOILING POINTS OF WATER.

Melting point and boiling point may be defined as follows:—

The *Melting Point* of a substance is the temperature at which the substance changes from the solid to the liquid state.

The *Boiling Point* of a liquid is the temperature at which the liquid boils, that is, the temperature at which bubbles of vapour appear at all points of the liquid.

Water boils at 100°C when the atmospheric pressure is 76 cm. of mercury. The following experiment shows that the boiling point of water varies according to the pressure on its surface.

EXPERIMENT XXVIII

To find the effect of change of pressure on the boiling point of water

The apparatus used in this experiment is shown in Fig. 129. A is a boiling flask, containing water. It is fitted with a tight fitting rubber stopper through which pass the thermometer T and the delivery tube BC, which is connected by pressure tubing to a glass T-piece T_1. The other ends of this T-piece are connected, one to a large winchester D and the other through a second T-piece T_2 to the pump at E and to the manometer M, which contains mercury. A Liebig's condenser surrounds the delivery tube BC and cold water, circulating through it, condenses the steam as it forms. It is essential that the apparatus should be absolutely airtight. This condition may be satisfied by sealing the joints with wax.

To perform the experiment, reduce the pressure inside the apparatus to about 30 cm. of mercury by applying a vacuum pump at E. Heat

the water in the flask to boiling point and read the thermometer T and the manometer M. Disconnect the pump, admit a little air by means of

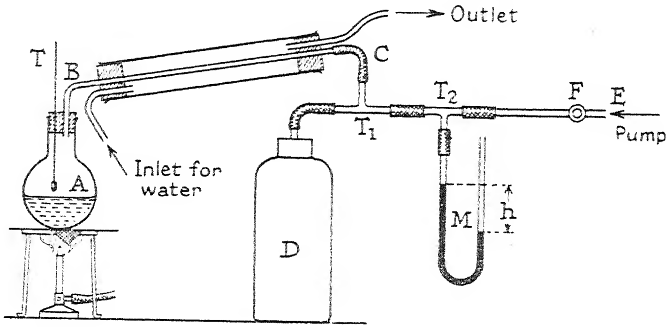


FIG. 129.

BOILING POINT AND PRESSURE APPARATUS.

the tap F and again read the thermometer and the manometer. Take a set of readings up to ordinary atmospheric pressure. To obtain pressures above atmospheric pressure, apply a compression pump at E and again read the thermometer and the manometer. Tabulate the results as below and plot a graph, boiling point on the horizontal axis and pressure on the vertical axis. N.B. The function of the winchester D is to supply a large volume of air so as to prevent fluctuations of pressure inside the apparatus.

A typical set of results (p. 130) and a graph (Fig. 130) are shown.

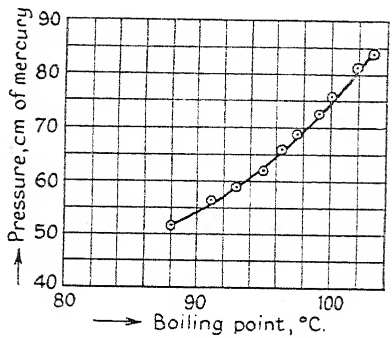


FIG. 130.

GRAPH SHOWING RELATION BETWEEN BOILING POINT OF WATER AND PRESSURE.

When steam is generated in the boiler of an engine, the pressure of the steam in the confined space above the water gradually increases. The increase of pressure is accompanied by an increase in the boiling point of the water and the process continues until the supply pressure is reached. The steam then passes into the cylinder.

Barometric Pressure = 75·7 cm. of mercury

Manometer reading H cm. of mercury	Absolute Pressure P = B + H cm. of mercury	Boiling Point °C
—24·0	51·7	88·0
—19·7	56·0	91·2
—16·7	59·0	93·0
—13·5	62·2	95·0
— 9·6	66·1	96·3
— 7·2	68·5	97·5
— 2·6	73·1	99·0
0	75·7	99·9
+ 5·8	81·5	102·0
+ 8·8	84·5	103·0

Latent Heat

During the change of state, represented by AB (Fig. 128), heat is supplied to the mixture of ice and water, but the temperature remains constant, viz., 0°C. In the operation represented by CD, heat is supplied to the water, and the temperature again remains constant, viz., 100°C. Heat that changes the state of a substance without change of temperalure is known as latent heat.

Thus latent heat of fusion must be imparted to a solid in order to change it into the liquid state, and latent heat of vaporisation must be imparted to a liquid to change it into the gaseous state, the temperature in each case remaining constant.

If the changes take place in the reverse order, a gas or a vapour on cooling reaches a temperature at which it changes into the liquid state and latent heat of vaporisation is evolved at constant temperature. On cooling through the liquid state, a temperature is reached at which the liquid changes into the solid state, latent heat of fusion being evolved in the process. This temperature is known as the Freezing Point of the liquid and is the same temperature as the melting point.

Experiment XXIX

To determine the melting point of naphthalene

Take a test tube, about 6″ long and ½″ diameter, and half fill it with solid naphthalene. Place the tube and its contents in a beaker containing

water and standing on a tripod, fitted with wire gauze. Place a Centigrade thermometer in the test tube and heat the water in the beaker until the thermometer registers 90°C. Now remove the test tube and support it in a stand. Allow the naphthalene, which is now in the liquid form, to cool and note its temperature every $\frac{1}{2}$ minute. Continue the cooling until a temperature of 50°C is reached and plot a graph, temperature vertical and time ($\frac{1}{2}$ minutes) horizontal. The horizontal portion BC of the graph (Fig. 131) represents the melting point of the naphthalene and its temperature can be read off from the axis of temperature.

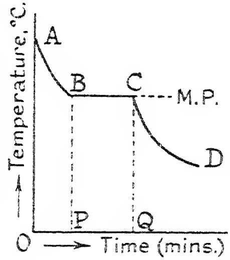


FIG. 131.

MELTING POINT OF NAPTHALENE BY COOLING CURVE.

During the interval of time represented by PQ, latent heat of fusion is evolved. The portions of the graph AB and CD represent the cooling of the liquid and solid naphthalene respectively.

Latent Heat of Fusion of Ice

The value of the latent heat of fusion of ice is 80 calories per gram. Thus to completely melt one gram of ice at 0°C, 80 calories must be added to the ice or to completely freeze one gram of water at 0°C, 80 calories must be withdrawn from the water. If 10 grams of ice are melted at 0°C, 80 × 10 calories must be added to the ice.

i.e., Latent heat of fusion gained or lost = Weight of Ice × Latent heat of fusion for 1 gram.

In the English system of units the latent heat of fusion of ice

= 80 C.H.U.s per lb. or $80 \times \frac{9}{5}$ B.Th.U.s per lb., i.e. 144 B.Th.U.s per lb.

Example. If 20 lbs. of water at 10°C are cooled to 0°C and then frozen, how much heat is withdrawn from the water?

Sensible heat lost	= 20 × (10 — 0) C.H.U.s
	= 200 C.H.U.s.
Latent heat of fusion lost	= 20 × 80 C.H.U.s
	= 1,600 C.H.U.s.
Heat withdrawn	= 200 C.H.U.s + 1,600 C.H.U.s
	= 1,800 C.H.U.s.

Experiment XXX

Determination of the Latent Heat of Fusion of Ice

Weigh a small copper calorimeter and weigh it again half filled with water. Enclose the calorimeter in a larger vessel and pack the space between the two vessels with cotton wool to minimise heat exchanges between the calorimeter and its surroundings. Note the initial temperature of the water and add pieces of dry ice about the size of a marble (N.B.—The pieces of ice can be dried with blotting paper) until the temperature of the calorimeter and contents falls about 10 degrees Centigrade. Stir the water, and when all the ice is melted note the final temperature. Weigh the calorimeter and contents to find the weight of the ice added. A typical set of results is shown below.

Weight of calorimeter	=	40·53 gms.
Weight of calorimeter + water	=	138·46 gms.
Weight of calorimeter + water + ice	=	150·50 gms.
Initial temperature of water	=	15°C.
Final temperature of water	=	5°C.
Sp. ht. of copper	=	0·1 cal. per gm. per deg. C.

Let L = the latent heat of fusion of ice in calories per gm.

Latent heat gained by ice	=	12·04L cals.
Sensible heat gained by water	=	12·04 × (5 — 0) cals.
Heat lost by water	=	97·93 × (15 — 5) cals.
Heat lost by calorimeter	=	40·53 × 0·1 × (15 — 5) cals.

Lat. Ht. gained by ice + Sensible heat gained by water = Heat lost by water + Heat lost by calorimeter

$$\therefore\ 12{\cdot}04L + 12{\cdot}04 \times 5 = 97{\cdot}93 \times 10 + 40{\cdot}53 \times 0{\cdot}1 \times 10$$

$$\therefore\ 12{\cdot}04L + 60{\cdot}2 = 979{\cdot}3 + 40{\cdot}53.$$

$$\text{i.e., } 12{\cdot}04L = 959{\cdot}6.$$

$$\therefore\ L = 79{\cdot}7 \text{ cals. per gm.}$$

Latent Heat of Steam

The value of the latent heat of steam, or the latent heat of vaporisation of water as it is sometimes called, is 540 calories per gram. That is, to completely boil away one gram of water at 100°C, 540 calories must be

added to the water, or to completely condense one gram of steam at 100°C, 540 calories must be withdrawn from the steam.

Thus the latent heat of steam = 540 cals. per gm., or 540 C.H.U.s per lb., or $540 \times \frac{9}{5}$ B.Th.U.s per lb., i.e., 972 B.Th.U.s per lb.

If 10 lbs. of water are boiled away at 100°C, 10×540 C.H.U.s must be added to the water, or if 10 lbs. of steam are condensed at 100°C, 10×540 C.H.U.s must be withdrawn from the steam.

Thus: Latent heat of Vaporisation added or withdrawn = Weight × Latent heat of vaporisation for unit weight.

Experiment XXXI

Determination of the Latent Heat of Steam

Arrange the apparatus shown in Fig. 132. The boiler A, containing a quantity of water, is closed by a cork through which passes a glass tube B which is connected to the steam drying tube C. Steam is generated in the boiler A and leaves the tube D. Dry steam enters the tube E and passes into the water contained in the double calorimeter F. The cotton wool between the inner and outer calorimeters reduces the heat losses to the surroundings to a minimum.

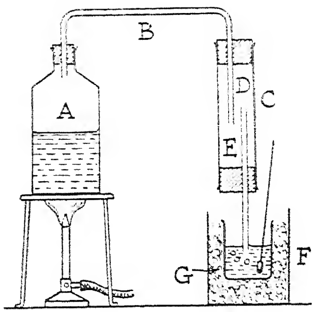


Fig. 132.
LATENT HEAT OF STEAM APPARATUS.

To perform the experiment, weigh the inner calorimeter G and weigh it again nearly filled with water. Allow the steam to escape for some time and then read the temperature of the water in the calorimeter. Immerse the end of the tube E under the surface of the water and pass steam until the temperature of the water rises to about 60°C. Stir the water and note its final steady temperature. Then weigh the calorimeter and contents to find the weight of the steam added. A typical set of results is shown below:

Wt. of calorimeter	= 40·53 gms.
Wt. of calorimeter + water	= 153·78 gms.
Wt. of calorimeter + water + steam	= 162·72 gms.
Initial temperature of water	= 15°C.
Final temperature of water	= 60°C.
Sp. Ht. of material of calorimeter	= 0·1 cal. per gm. per deg. C.

Let L = latent heat of steam in calories per gram.

Latent heat lost by steam $= 8 \cdot 94$ L cals.

Sensible heat lost by water $= 8 \cdot 94 \times (100 - 60)$ cals.
$= 357 \cdot 6$ cals.

Heat gained by water $= 113 \cdot 25 \times (60 - 15)$ cals.
$= 5096$ cals.

Heat gained by calorimeter $= 40 \cdot 53 \times 0 \cdot 1 \times (60 - 15)$ cals.
$= 182 \cdot 5$ cals.

Lat. Ht. lost by steam	+	Sensible heat lost by water	=	Heat gained by water	+	Ht. gained by calorimeter.
8·94L	+	357·6	=	5096	+	182·5

$\therefore$ 8·94L = 4921

$\therefore$ L = 550 cals. per gm.

Example. A steel boiler, weighing 200 lbs., contains 1,000 lbs. of water at 15°C. How much heat must be imparted to the boiler and contents to raise the temperature to boiling point and to boil away half the water? Latent heat of steam = 540 C.H.U.s per lb.; Sp. ht. of steel = 0·1 C.H.U. per lb. per deg. C.

Sensible heated gained by water $= 1{,}000 \times (100 - 15)$ C.H.U.s
$= 85{,}000$ C.H.U.s.

Heat gained by boiler $= 200 \times 0 \cdot 1 \times (100 - 15)$ C.H.U.s
$= 1{,}700$ C.H.U.s.

Latent heat gained by water $= 500 \times 540$ C.H.U.s
$= 270{,}000$ C.H.U.s

Total quantity of heat gained $= 270{,}000$ C.H.U.s $+ 85{,}000$ C.H.U.s $+ 1{,}700$ C.H.U.s
$= 356{,}700$ C.H.U.s.

Example. What weight of steam at 212°F must be passed into a steel tank, weighing 300 lbs. and containing 2,000 lbs. of water at 60°F, to raise the temperature of the tank and contents to 80°F? Latent Heat of steam = 970 B.Th.U.s per lb.; Sp. ht. of steel = 0·1 B.Th.U. per lb. per deg. F.

Let w = weight of steam in lbs.

Latent heat lost by steam $= 970w$ B.Th.U.s.

Sensible heat lost by water $= w \times (212 - 80)$ B.Th.U.s
$= 132w$ B.Th.U.s.

$$\text{Heat gained by water} = 2{,}000 \times (80 - 60) \text{ B.Th.U.s} = 40{,}000 \text{ B.Th.U.s.}$$

$$\text{Heat gained by tank} = 300 \times 0{\cdot}1 \times (80 - 60) \text{ B.Th.U.s} = 600 \text{ B.Th.U.s.}$$

$$\begin{array}{ccccccc} \text{Lat. Ht. lost by steam} & + & \text{Sensible heat lost by water} & = & \text{Heat gained by water} & + & \text{Heat gained by tank.} \\ \therefore 970w & + & 132w & = & 40{,}000 & + & 600 \end{array}$$

$$\therefore 1{,}102w = 40{,}600$$

$$\therefore w = 36{\cdot}8 \text{ lbs. of steam.}$$

Evaporation

Boiling or ebullition, as it is sometimes called, is the conversion of a liquid into its gaseous state at one particular temperature, viz., boiling point, and latent heat of vaporisation must be added to the liquid to produce this change of state. But a liquid changes into its gaseous state at all temperatures by a process known as evaporation. In the case of ebullition bubbles of vapour appear at all points of the liquid whereas evaporation is a surface effect in which the molecules escape from the surface of the liquid into the space above. Latent heat of vaporisation is also needed to change the state in the process of evaporation, and, since there is no external source of heat, the heat comes from the liquid itself, thus producing a cooling of the liquid.

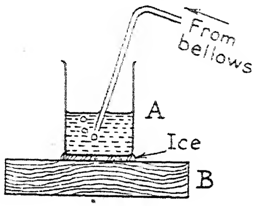


FIG. 133.

PRODUCTION OF ICE BY RAPID EVAPORATION OF ETHER.

When a small copper vessel A which contains a quantity of ether is placed on a large drop of water on a block of wood B, so that a film of water is formed between the vessel and the block, and air from a foot bellows is bubbled through the ether, the copper vessel is frozen to the block (Fig. 133). The rapid evaporation of the ether which is a very volatile liquid is accompanied by an absorption of heat. Some of this heat comes from the water under the vessel. The water cools to freezing point and then solidifies.

Factors affecting the rate of evaporation of a liquid

Since evaporation is a surface effect, the greater the surface area the greater is the rate of evaporation. In the experiment described above, the air bubbles provide a much greater surface area and the rate of

evaporation is very much increased. The rate of evaporation of a liquid also depends on the amount of its vapour already present in the space above the liquid. If the air above a sheet of water contains only a small quantity of water vapour, evaporation proceeds at a good rate; but the nearer the air is to saturation point the smaller will be the rate of evaporation; in fact, when the air above the water is saturated with water vapour no evaporation takes place. It can now be understood why winds play such a great part in nature by removing the water vapour above sheets of water and allowing evaporation to continue.

Cooling by evaporation is utilised in practice in many ways. Thus in hot countries water is kept cool by storing it in earthenware jars which are slightly porous. The jars are always wet on the outside and evaporation goes on continuously, thus keeping the water in the jars cool. Liquids are also kept cool by placing them in earthenware jars, covering them with damp cloths and keeping them in air draughts.

Cooling due to expansion of a gas

Another method of producing cooling is to allow a gas under pressure to expand into a vessel in which the pressure is low, without allowing heat to enter from outside. The molecules of a gas are held together by forces of attraction between them and when the gas expands work is done against these attractive forces. To produce this work, heat is taken from the gas itself and the gas cools (see Ch. XII).

Refrigeration

Both the principles of cooling by evaporation of a liquid and by expansion of its vapour are applied in some types of refrigeration plant (Fig. 134). Liquid ammonia under pressure is forced by a pump A through tubes surrounded by water sprinklers to remove the heat produced in compression and then through a fine orifice B into a series of tubes C which have been evacuated of air. Vaporisation takes place at the orifice and then expansion. The cooled vapour passes through the tubes which are immersed in a brine bath D and then passes back to the pump. The brine is cooled to a temperature below 0°C and the compartments E, immersed in the bath, can be used for cold storage.

Exercises XI

1. In what way is the volume of a given substance usually affected by change of temperature? Describe experiments which illustrate this property in the case of (*a*) a solid and (*b*) a liquid. Explain how

the volume changes can be utilised in the construction of a mercurial thermometer, and point out any source of error that may be involved in calibrating the thermometer.

(C. G. L. I.; Hand. S.)

2. Why is mercury generally used in making thermometers? If you were provided with a length of capillary tubing and some clean mercury, explain how you would make and graduate a Fahrenheit thermometer.

(C. G. L. I.; Hand. S.)

3. Find the Fahrenheit temperatures which correspond to (*a*) 15°C, (*b*) 232°C, (*c*) —10°C.

4. Find the Centigrade temperatures which correspond to (*a*) 60°F, (*b*) 100°F, (*c*) 0°F.

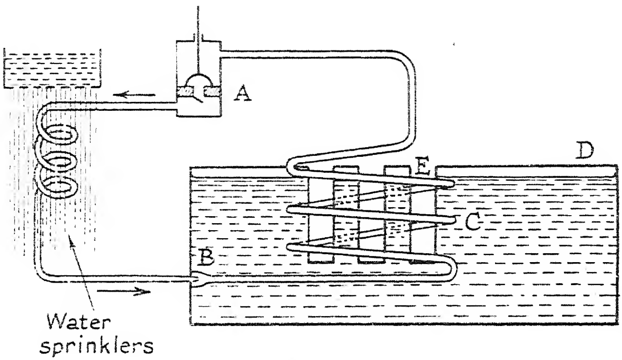


FIG. 134.

REFRIGERATION PLANT.

5. Wrought-iron piping, 30 feet long at 60°F, has water at a temperature of 180°F running through it for some time. If the coefficient of linear expansion of wrought iron is 0·0000067 per °F, calculate the increase in length.

6. 200 lbs. of water pass through a condenser per minute. The steady temperatures of the entering and leaving water are 50·5°F and 95°F respectively. Calculate the quantity of heat taken away by the condensing water per hour.

7. An iron tank, weighing 200 lbs., contains 30 gallons of water at 60°F. How much heat must be supplied to the tank and its contents in order to raise the temperature to 75°F? (Specific Heat of iron = 0·12; 1 gallon of water weighs 10 lbs.)

8. What volume changes and what energy changes take place during the whole process of changing ice at 0°C into water at 0°C, and finally into steam at 100°C ?

Illustrate the effects and, where possible, useful applications of these changes.

(C. G. L. I.; Hand. S.)

9. Describe a method for finding the linear coefficient of expansion of a metal with fair accuracy.

How is expansion important in the making of castings ? What is the difference between a " shrink fit " and an " expansion fit " ?

(C. G. L. I.; Hand. S.)

10. What are the principal sources of error in a mercury-filled thermometer ? In what ways is the use of such a thermometer limited ?

Describe one method of measuring high temperatures.

(C. G. L. I.; Hand. S.)

11. Distinguish between " sensible heat " and " latent heat," and explain the heat transfers which take place in the operation of soft-soldering.

(C. G. L. I.; Hand. S.)

12. How many units of heat are required to warm an aluminium kettle weighing 500 grams and its contents, 1,500 grams of water, to a temperature of 90°C on a day when the air temperature is 12°C ? Specific heat of aluminium = 0·21.

(C. G. L. I.; Hand. S.)

13. What is meant by the term " temperature " ? Describe and explain the working of two instruments by means of which temperature may be measured.

(C. G. L. I.; Hand. S.)

CHAPTER XII

HEAT (B)

TRANSFERENCE OF HEAT

CONDUCTION OF HEAT

When the end of an iron poker is placed in the fire and the handle is held in the hand, heat passes from the fire, along the poker, to the hand. This mode of transfer of heat is known as conduction and takes place mainly in solids. In the case of the poker, the heat passes from the hot end to the cold end by the particles transferring the heat from one to the next and so on and the particles do not move with the heat.

Fig. 135 shows a metal tank, filled with water, with circular holes in one side. The holes are closed by corks and bars of different materials, copper, iron, aluminium and wood pass through the corks. These bars have equal diameters and equal weights (e.g., ten-gram weights) are suspended by threads at equal distances from the tank. The threads are fastened to the rods by paraffin wax and the water is heated to boiling point by bunsen burners. After a time the weights begin to fall off the bars in the following order: copper, iron, aluminium and wood. Before a weight can fall, the point of the bar to which it is fastened must reach the melting point of the wax and the order in which the weights fall gives the order of conducting power of the materials.

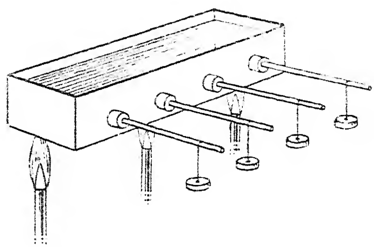


FIG. 135.

APPARATUS FOR COMPARING THE CONDUCTING POWERS OF DIFFERENT MATERIALS.

When a new sheet of wire gauze of small mesh is held about two inches above a bunsen burner (Fig. 136 (*a*)) and a light is applied below the gauze with the gas turned on, the flame extends only to the gauze. Again when the light is applied above the gauze the flame does not extend below (Fig. 136(*b*)). In each case the wire gauze, being a good conductor of heat, conducts the heat away from the gas and the temperature of the gas does not become high enough to ignite.

Fig. 137 shows a compound bar made of brass and wood. A sheet of foolscap paper is wrapped round the joint and the flame of a bunsen burner is allowed to play on the paper. The paper over the wood is burnt while that over the brass is unaffected. This is because the

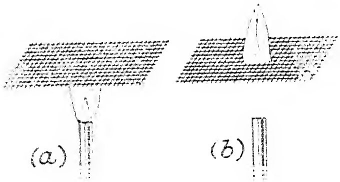


FIG. 136.

APPARATUS TO ILLUSTRATE THE PRINCIPLE OF THE FLAME SAFETY LAMP.

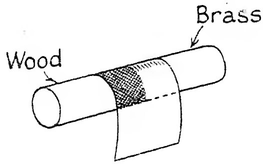


FIG. 137.

COMPOUND BAR OF BRASS AND WOOD.

brass conducts the heat away from the flame rapidly and the paper over it does not reach its ignition point. The wood, being a poor conductor of heat, cannot conduct the heat away from the flame fast enough and the paper covering it reaches its ignition temperature and then burns.

Practical Applications of Conduction

We have seen that substances can be arranged in the order of their thermal conducting power. Good thermal conductors allow heat to pass through them easily while bad conductors allow heat to pass through them only with difficulty. Both good and bad conductors have their uses in industry. Thus the " bit " of a soldering iron is made of copper, a good conductor, through which the heat can spread, whereas the handle is made of wood or bakelite, both of which are poor conductors of heat. The handle can therefore be held for long periods without becoming too hot.

Felt and asbestos, being poor conductors of heat, are used for " lagging " steam pipes in order to keep the cold air from coming into contact with the pipes. The inner surface of the felt is at 100°C, whereas the outer surface is not much above air temperature.

Another example of a poor conductor is the effect of the scale formed on the inner surface of a boiler. The scale is a poor conductor of heat and it reduces the heating surface of the boiler. In order for the heat to pass from the fire to the water the temperature of the metal, in contact with the scale, becomes very high. In the case of the portions of the boiler, free from scale, there is no excessive heating. These differences

in temperature between the various portions of the boiler cause unequal expansion and detrimental stresses are produced in the metal.

The valves of motor engines often tend to become overheated, and to prevent this the valve is drilled down the centre of the stem and filled in with copper, a better conductor than steel. This arrangement allows the heat to be conducted away.

The flame safety lamp, invented by Sir Humphry Davy, is a practical example of the wire gauze experiment described above. The gauze of the lamp does not allow the flame inside to spread to the outside. This is essential, as inflammable gases are present in the mine and explosions are thereby prevented.

Convection of Heat

If a rectangular glass tube ABCD, with a reservoir R in its upper branch, is filled with water (Fig. 138) and a small quantity of red ink is placed in the reservoir, when the corner D is heated the coloured water descends the branch BC. The water at D expands, decreases in density and rises up the branch DA and a cold water current descends BC to take its place. This mode of transfer of heat is known as convection. The heat is carried by the stream of moving particles, which is called a convection current.

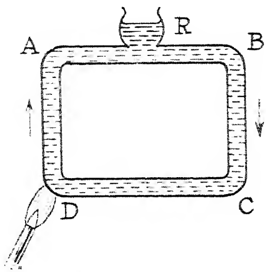


Fig. 138.
CONVECTION CURRENTS IN WATER.

Practical Applications

The domestic hot water supply is shown in Fig. 139. Water is heated in the boiler A and passes up the pipe B, into the top of the cistern C, and a branch current passes through the radiator R. Hot water from the cistern then passes up the pipe D, a branch current runs along the pipe E to the sink, bath, etc., while the remainder passes up the pipe F to the cold water tank at the top of the building. A cold water current descends the pipe H and enters the bottom of the cistern. Another pipe K conveys cold water from the bottom of the cistern to the bottom of the boiler.

It should be noted that the hot water at the top of the cistern is less dense than the cold water at the bottom and mixing cannot take place. Also, in this type of heating system the hot water pipes leave from the

top of the boiler and cistern whereas the cold water pipes enter at the bottom.

In central heating the same principle is applied. Hot water passes

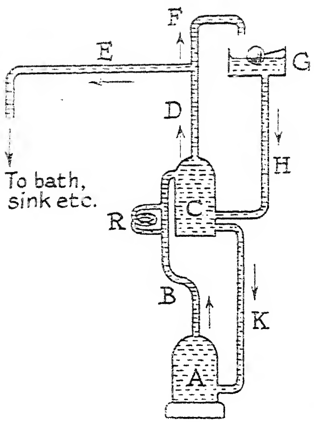


FIG. 139.
DOMESTIC HOT WATER SUPPLY.

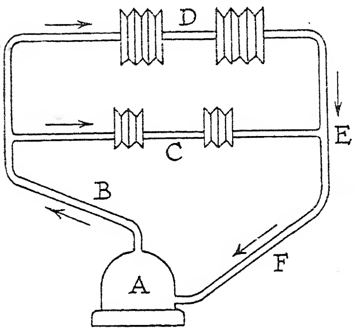


FIG. 140.
CENTRAL HEATING.

from the boiler A (Fig. 140) up the pipe B, through the radiators on the first floor C and a branch current passes through the radiators on the floor D. The branch currents recombine at E and flow down the return cold water pipe F to the bottom of the boiler.

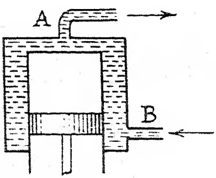


FIG. 141.
CONVECTION COOLING OF A PETROL ENGINE CYLINDER.

Fig. 141 shows how the principle of convection currents is applied in the cooling of the cylinder of a petrol engine. The frequent explosions in the cylinder produce a great quantity of heat, which causes the cylinder to become red hot unless some cooling system is employed. The cylinder is kept surrounded with water which rises up the pipe A as it is heated and cold water enters by the pipe B to take its place.

Convection Currents in Air

Fig. 142 shows a large box with a glass front, supplied with two chimneys A and B. A burning candle is placed below the chimney B, and when a piece of burning brown paper is held over the chimney A

a current of black smoke is plainly visible. The current passes down the chimney A and up the chimney B. The air above the candle is heated, expands and rises while a cold air current descends the chimney A to take its place.

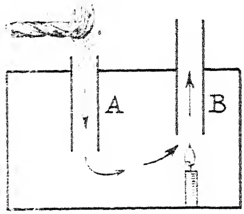


FIG. 142.
CONVECTION CURRENTS IN AIR.

This principle used to be applied in the ventilation of a coal mine. A large fire was kept burning at the bottom of the upshaft. Nowadays forced convection is applied by having a fan drift at the top of the upshaft. Rooms are ventilated on the same principle. Warm air, being less dense than cold air, rises and passes through the windows or the ventilators near the ceiling, while cold air enters under the door or through the ventilators near the floor.

RADIATION

The effect of placing a fire screen in front of a warm fire is well known. To anyone sitting behind the screen, some of the heat from the fire is cut off. Evidently this heat which is known as radiant heat cannot pass round the edges of the screen and it travels in straight lines in the same way as light. Radiant heat requires no material medium for its propagation as it can pass through a vacuum. Thus radiant heat passes from the sun to the earth through the vacuous space between them.

FACTORS WHICH AFFECT THE RATE OF COOLING OF A BODY

When a quantity of hot water is allowed to cool in a copper calorimeter, blackened with soot, and the temperature is read every minute, a curve connecting temperature and time (minutes) can be drawn (Fig. 143(1)). When the experiment is repeated with the surface of the calorimeter polished but with the same quantity of water and the same initial temperature, curve (2) is obtained. When the experiment is again repeated with the polished calorimeter surrounded with felt and the other conditions the same as before, curve (3) is obtained.

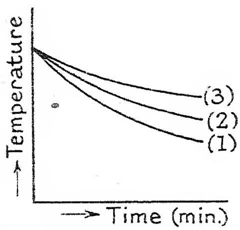


FIG. 143.
COOLING OF A BODY UNDER DIFFERENT SURFACE CONDITIONS.

The graphs show that a polished surface does not radiate heat so well as a dull surface and that a surface "lagged" with felt does

not radiate heat so well as a surface open to the air. In the case of the "lagged" surface, convection cooling is very much reduced. If the calorimeter were enclosed in a vessel, evacuated of air, the convection cooling would be entirely eliminated.

Radiators and Absorbers

Black surfaces are good radiators when hot and good absorbers of radiant heat when cold. On the other hand, highly polished metallic surfaces are poor radiators when hot and poor absorbers when cold, since they reflect nearly all the radiant heat incident upon them.

Practical Applications

The Radiator of a Car

Fig. 144 shows the cooling system used with the cylinders of a car. One cylinder A is shown and the hot water in the jacket round it rises up the pipe B and enters the top of the radiator C. The water runs through the interspaces of the radiator (shown inset) from the top to the bottom and then up the pipe D, back to the cylinder jacket. Since the water which passes down the radiator has to be cooled a considerable amount, it is so designed that as much area of surface as possible is in contact with the air. The small holes give this increased area. Air is drawn through the holes by a fan F, geared to the crankshaft, and the forced convection produced by the fan increases the rate of cooling.

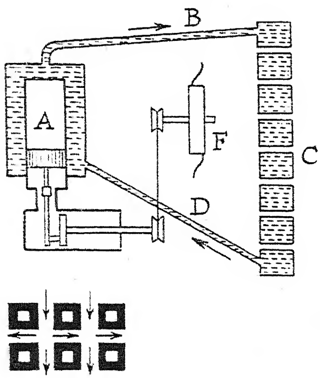


Fig. 144.
RADIATOR OF A CAR.

Conduction, convection and radiation play their parts in the cooling of a body but, in the case of bodies at moderately high temperatures, convection currents in air contribute by far the greatest cooling effect. In appliances in which rapid cooling is vital we have seen that it is necessary to have as great a surface area as possible in order to increase this effect. Thus, in the case of the single-cylinder engine of a motor cycle, additional area of surface is obtained by the metallic fins which project from the surface. The air in contact with these fins carries the heat away and the necessary cooling is obtained.

The Vacuum Flask

A hot body cools (*a*) by conduction through the base into the surface on which it rests, (*b*) by convection currents in the air, and (*c*) by direct radiation. We have seen that convection cooling is by far the greatest effect and this principle is applied in the vacuum or thermos flask. The vacuum flask (Fig. 145) consists of a double-walled glass vessel A, the space between the walls being evacuated of air. The outside of the inner wall and the inside of the outer wall are silvered. The flask rests in a cardboard container B, being separated from it by pieces of cork. The greatest source of cooling, viz., convection cooling, is eliminated by the vacuum. Conduction of heat is cut out by the cork separators, cork being a poor thermal conductor, and radiation cooling, which is only small in any case, is practically eliminated by the silvered surfaces. Any radiant heat that leaves the inner wall is nearly all reflected back by the silvering on the outer wall (see inset) because polished surfaces are poor absorbers and good reflectors.

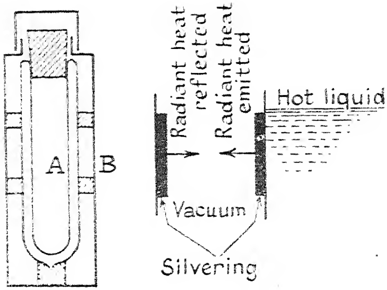


Fig. 145.
VACUUM FLASK.

Thermos flasks are used not only for keeping liquids hot but also for keeping liquids cold. Thus, in low-temperature storage, quantities of liquid air (B. Pt. —182°C), liquid hydrogen and liquid helium may be stored in vacuum flasks for lengthy periods.

The Mechanical Equivalent of Heat

We have seen in Ch. V that energy may have several forms, viz., heat, work, potential and kinetic energy (i.e., mechanical energy), and also that energy can be neither created nor destroyed. But energy of one form may be transformed into energy of another form. Thus the work expended in overcoming friction produces heat, as in the case of an axle rotating on its bearings. The mechanical or kinetic energy of the rotating armature of a dynamo (see Ch. XVII) is transformed into the energy of an electric current, which in turn is transformed into heat (see Ch. XVIII). Again the chemical energy of dilute sulphuric acid acting on zinc results in a generation of heat (see Ch. XV), and vice

versa the heat acting on combustible materials produces burning, which is known as oxidation.

Joule's Equivalent

All forms of energy can be measured in a unit called the Joule, after a scientist named Joule (see Ch. XVIII), but work, kinetic energy and potential energy are generally measured in foot pounds. Joule enunciated a very important law, viz.: *When a definite amount of work is expended an equivalent amount of heat appears, and when a definite amount of heat is expended an equivalent amount of work appears.* Thus there is a definite relationship between the unit of work and the unit of heat, viz.:—

$$1 \text{ Calorie} = 4{\cdot}18 \text{ joules.}$$
$$1 \text{ C.H.U.} = 1{,}400 \text{ ft. lbs.}$$
$$1 \text{ B.Th.U.} = 780 \text{ ft. lbs.}$$

Example. The reaction of the bearings to an axle, of diameter 2 inches, is 360 lbs. and the coefficient of friction is 0·1. Find the heat produced in the bearings per hour, if the axle rotates at 400 R.P.M.

$$\begin{aligned}
\text{Frictional resistance} &= 360 \times 0{\cdot}1 \text{ lbs.} \\
&= 36 \text{ lbs.} \\
\text{Work done per revolution} &= 36 \times 2 \times 3{\cdot}14 \times \tfrac{1}{12} \text{ ft. lbs.} \\
&= 18{\cdot}84 \text{ ft. lbs.} \\
\text{Work done per hour} &= 18{\cdot}84 \times 400 \times 60 \text{ ft. lbs.} \\
&= 452{,}160 \text{ ft. lbs.} \\
\text{Heat produced} &= \frac{452{,}160}{1{,}400} \text{ C.H.U.s} \\
&= 323 \text{ C.H.U.s.}
\end{aligned}$$

The Steam Engine

The principle of the conversion of heat into work is utilised in the steam engine. The heat supplied to the water in the boiler produces steam under high pressure and, as the steam expands in the cylinder, it supplies the work required to drive the piston.

Fig. 146 shows some of the chief features of a reciprocating steam engine. The piston P, moving in the cylinder W, is connected by the piston rod L to the cross head G. The connecting rod M is pinned at one end to the end of the crank S and at the other end to the cross head. The piston P is moved backwards and forwards in the cylinder by the pressure of the steam, first acting on one side and then on the other and

the connecting rod causes the crankshaft T to rotate. Steam from the engine boiler enters the steam chest Q at the opening A and the entrance of the steam to the cylinder through either of the ports B and C is controlled by the slide valve F. This valve is driven by means of a device called an eccentric which consists of a circular disc V, mounted eccentrically on the crankshaft T. The strap R, to which is attached one end of the eccentric rod N, fits on the disc and does not rotate as the disc rotates (see inset). The other end of the eccentric rod is pinned

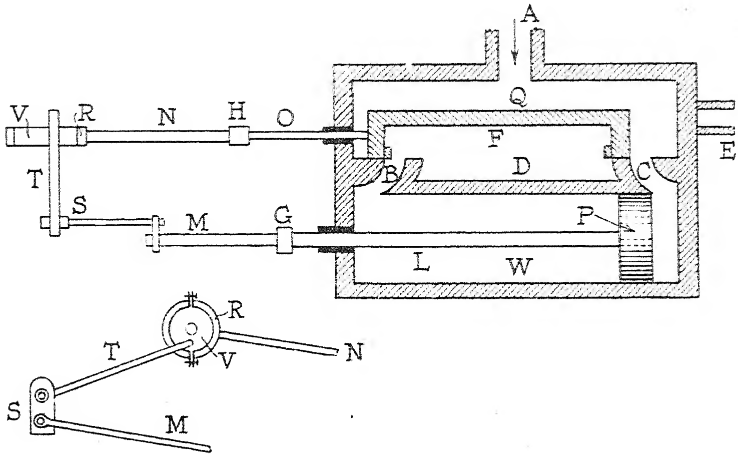


FIG. 146.

CYLINDER OF A RECIPROCATING STEAM ENGINE.

to the valve rod O at H, and as the crankshaft rotates the slide valve moves backwards and forwards alongside the cylinder.

The slide valve is designed for either expansive or non-expansive working. In the non-expansive type one port remains open to the steam chest Q and the other is connected to the exhaust D during practically the whole of a stroke. Let us consider this type first. When the piston is in the position shown in Fig. 147(*a*), steam enters the port B and drives the piston to the right. When the piston has reached the end of this stroke (Fig. 147(*b*)), the slide valve closes both ports and the inertia of the flywheel which is mounted on the crankshaft causes the piston to move to the left. In the position shown in Fig. 147(*c*), the port B becomes connected to the exhaust and the port C to the steam chest. When the piston has reached its extreme position on the left (Fig. 147 (*d*)), both ports are again closed and the inertia of the flywheel again

forces the piston to the right. In this manner the to-and-fro motion of the piston continues.

In the expansion working type, used in modern steam engines, the slide valve has a lap attached to it (Fig. 148). The lap causes the steam to be shut off from the steam chest when a certain fraction of a stroke is

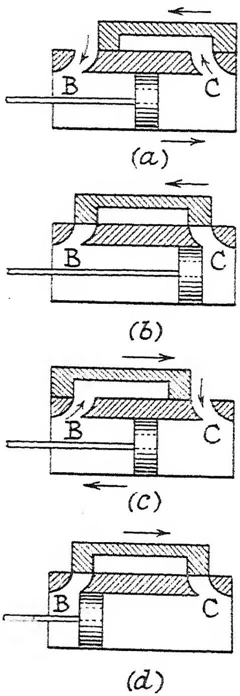


FIG. 147.
SLIDE VALVE—NON-EXPANSIVE WORKING.

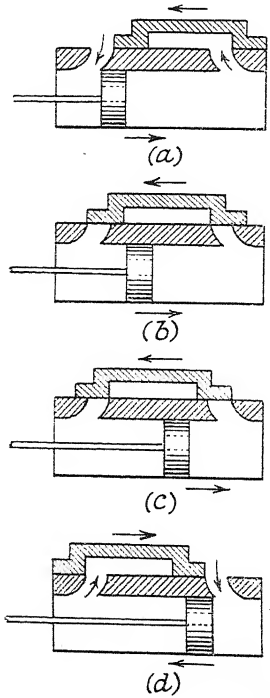


FIG. 148.
SLIDE VALVE—EXPANSIVE WORKING.

accomplished. Then the expansion of the steam under pressure drives the piston nearly to the end of the cylinder, when the operation is repeated in the opposite direction. Figs. 148(*a*), (*b*), (*c*) and (*d*) show the effect of the lap on the admittance of the steam to the ports.

THE PETROL ENGINE

An engine in which the combustion of the fuel takes place in the cylinder is known as an internal-combustion engine, and the fuel used is generally vaporised petrol.

Fig. 149 shows the chief features of a single-cylinder engine used in a motor cycle. In motor vehicles in which several cylinders are used, the general principles about to be outlined are the same. A is the piston which moves in the cylinder D, and B is the connecting rod, one end of which is pinned to the piston and the other end to the crank of the heavy cast-iron wheel C. This wheel serves the same purpose as the flywheel of a steam engine. Two openings E and F, fitted with mushroom valves V_1 and V_2, lead, one to the carburettor and the other to the

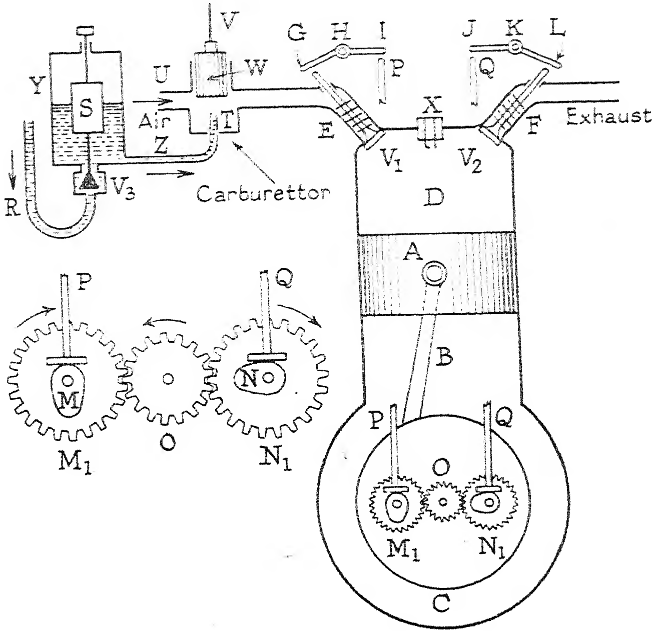


FIG. 149.
PETROL ENGINE.

exhaust pipe, which is open to the atmosphere. In this type of engine there are four strokes in the cycle of operations: (*a*) the induction or charging stroke, (*b*) the compression stroke, (*c*) the power or expansion stroke and (*d*) the exhaust stroke. It will be seen from the diagram that a downward and upward stroke of the piston corresponds to one complete revolution of the crankshaft, and for the complete cycle there are two revolutions of the crankshaft.

At the beginning of the charging stroke, the piston is at the top of the

cylinder where there is a small clearance. As the piston moves down (charging stroke) a mixture of air and petrol vapour is drawn from the carburettor, through the valve V_1. During this stroke the exhaust valve V_2 is closed. The kinetic energy of the wheel C now causes the piston to ascend the cylinder (compression stroke) and the mixture of air and petrol vapour is compressed, the valves V_1 and V_2 being closed during this stroke. The spark from the sparking plug X, operated from the magneto, then ignites the gaseous mixture and the explosion drives the piston down the cylinder (power stroke), the valves V_1 and V_2 being closed during this stroke. Then on the upward stroke (exhaust stroke) the products of combustion are forced through the valve V_2 into the atmosphere, the valve V_1 being closed.

It is important to realise that the valves V_1 and V_2 must be opened and closed at the appropriate instants during the cycle of operations. This is known as valve timing. In the type of engine considered, the valves are operated by rocking levers GHI and LKJ, pivoted at H and K respectively, and gearing worked from the crankshaft. The latter consists of gear wheels, pear-shaped devices known as cams, and push rods (see inset). The lower ends of the push rods rest on the cams M and N which are fixed to the spindles of the pinions M_1 and N_1 respectively, while their upper ends extend to the ends I and J of the rocking levers, a small clearance being left to allow for expansion. A small clearance is also left between the ends G and L of the rocking levers and the upper ends of the valve rods. The pinions M_1 and N_1 are operated by the gear wheel O which is mounted on the crankshaft, and the number of teeth in the gear wheels is so chosen that the correct valve timing is obtained.

The Carburettor

Petrol from the tank descends the tube R and enters the float chamber Y, through a valve V_3 at the bottom. To control the supply, when the petrol reaches a certain level, the hollow cylinder S rises and the valve V_3 is closed. This arrangement automatically controls the supply of petrol entering the carburettor. The petrol then flows along the pipe Z to the jet T, where it is sprayed into the air which enters by the opening U. A throttle control wire V controls the supply of air by means of the cylinder W which is moved up and down in front of the air inlet. The mixture of air and petrol vapour then passes through the opening E into the cylinder D.

Exercises XII

1. Illustrate two ways in which the rate of loss of heat may be (*a*) diminished, (*b*) increased.

(C. G. L. I.; Hand. S. Part question.)

2. Make clear the difference between conduction and convection of heat. Explain an important transformation of radiant heat into convected heat.

(C. G. L. I.; Hand. S.)

3. Explain in fair detail the working of one cylinder of a slide valve engine. Make clear the part played by heat energy.

(C. G. L. I.; Hand. S.)

4. Illustrate and explain the workshop use of three materials which are poor conductors of heat. How could the conducting power of two of these materials be compared ?

(C. G. L. I.; Hand. S.)

5. Explain the purpose and operation of each of three of the following: (*a*) A paraffin lamp chimney, (*b*) a tall mill chimney, (*c*) a ventilator cowl, (*d*) a Davy safety lamp.

(C. G. L. I.; Hand. S.)

6. It is said that heat is a form of energy. What does this mean ? How can it be demonstrated by experiment that there is a definite relationship between heat and work ? Explain shortly the conversion of heat energy into work by the help of a petrol engine. What happens to the energy of the spark ?

(C. G. L. I.; Hand. S.)

CHAPTER XIII

THE PROPERTIES OF MATERIALS

The Properties of Solids

All solids possess some of the following properties, viz., porosity, cohesion, ductility, malleability, hardness, etc.

Porosity

It is well known that water can be filtered through a piece of blotting paper or can be absorbed by a lump of sugar. This property indicates that small holes or pores exist between the particles of these substances. Many solids possess this property to a greater or lesser extent and are said to be porous. Unglazed brick, earthenware, timber, etc., possess porosity to an appreciable extent, whereas metals such as steel, aluminium, etc., are non-porous. A knowledge of the relative porosities of woods is important, for porosity is closely allied to strength and density and affects surface conditions, viz., the suitability to receive paint or polish.

Moisture Content

The pores of freshly felled timber are filled with moisture and the timber is said to have a large moisture content. Thus in the case of the swamp cypress for example, the weight of the moisture is more than the weight of the dry timber. In order to make the timber reliable and workable, this moisture content has to be reduced considerably. This is done by a process known as seasoning.

The amount of moisture in a piece of wood is expressed as a percentage. Thus:—

$$\text{Percentage moisture content} = \frac{\text{weight of moisture present}}{\text{weight of dried sample}} \times 100$$

$$= \frac{\text{Initial weight of sample} - \text{weight of dried sample}}{\text{weight of dried sample}} \times 100$$

Experiment XXXII

To determine the moisture content of a sample of wood

The sample to be tested is generally a piece of board about ½ inch thick, including the full cross section, and free from knots. Weigh the sample on a sensitive balance to the nearest ·005 of a gram. Now dry the sample in an oven and, after cooling, again weigh. Dry the sample still further, to be sure that all the moisture is driven off, and weigh again. Calculate the percentage moisture content from the formula above.

The Xylol Method for the determination of moisture content

The method outlined above is unsuitable for timbers containing a large quantity of oil or resin, as some of these are driven off in the drying process. In the method now to be described, the sample of wood, in small pieces, is weighed on a common balance. The pieces of wood are then transferred to a flask A (Fig. 150) which contains a quantity of Xylol. This liquid is a coal tar oil which does not mix with water. The flask A is fitted with an airtight stopper, through which passes the delivery tube BC which is surrounded by a Liebig's condenser D. A bath E, containing paraffin wax, surrounds the flask. The bath rests on a sand tray, supported on a tripod, and a bunsen burner is applied. The Xylol dissolves any resin or oil contained in the wood, and is vaporised at 140°C. The Xylol vapour passes along the tube BC and is condensed. Any moisture in the wood is taken over in the form of steam. After being condensed, the Xylol and the water flow into a measuring cylinder F, where the water separates from the Xylol. Two distinct layers are formed, the water being below. From the volume of water collected, its weight can be determined and its moisture content calculated from the relation:—

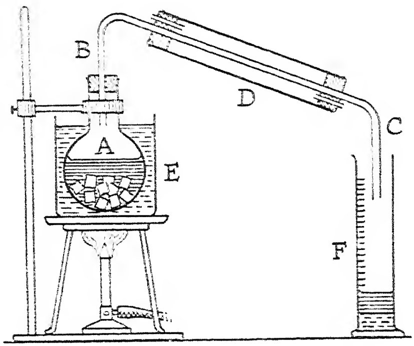


Fig. 150.

XYLOL TEST FOR MOISTURE CONTENT.

$$\text{Percentage moisture content} = \frac{\text{Wt. of moisture}}{\text{Wt. of dried wood}} \times 100$$

Effect of moisture on the dimensions of pieces of timber

When a piece of timber is soaked in water it is said to "swell." This means that its dimensions increase. On the other hand, a piece of timber which is saturated with moisture shrinks to a considerable extent when dried.

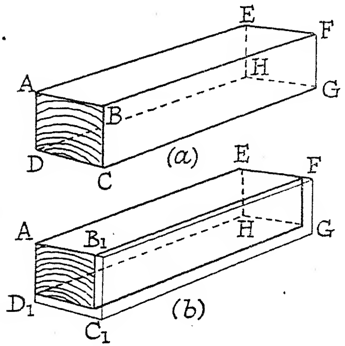


Fig. 151.
SHRINKAGE OF TIMBER DUE TO SEASONING.

A board ABCDEFGH, cut from a tree trunk, is shown in Fig. 151 (*a*). The side AB is tangential to the annual growth rings, whereas the side AD cuts across these rings approximately at right angles and is radial to them. As we have seen, when timber is felled it contains a large quantity of water but after seasoning the boards cut from it shrink a considerable amount, as shown in Fig. 151(*b*). Thus the side AB shrinks to AB_1 and the side AD to AD_1.

The following table gives the percentage shrinking for various timbers, based on the dimensions when freshly felled or green, and when oven dried.

TABLE IV

Material	Percentage Shrinkage	
	Radial to the rings	Tangential to the rings
Alder red	4·4	7·3
Beech	4·6	10·5
Elder	4·4	9·0
White oak	4·1	6·4
Yellow birch.. ..	6·9	8·9
Black walnut ..	5·2	7·1
Cuban pine	5·9	7·5

The longitudinal shrinkage along the length BF is negligible.

CHANGE IN LENGTH OF A SPECIMEN OF TIMBER, DUE TO CHANGE IN MOISTURE CONTENT

The change in length of a specimen of timber, due to moisture content, can be determined by means of the simple apparatus shown in front elevation in Fig. 152. A is a steel base, to which four steel uprights are fixed. These uprights support horizontal steel platforms G and H. BC is the specimen of timber, either rectangular or circular in section, which rests in a depression in the base A and projects at its upper end through a circular hole in the platform G. A steel disc E, to which is attached a cylindrical steel rod FQ, rests on the upper end of the specimen and the rod passes through a circular hole in the platform H. A steel upright RO is fixed to the platform H, and at O a lever OP is hinged. The lever rests in a V notch at the end of the rod FQ and its free end moves along the scale S, which is supported by a stand (not shown in the diagram). One end of a helical spring S_1, composed of steel wire, is fixed to a point on the lever and the other end is soldered to the end of the screw S_2. By means of this screw, the spring is stretched and the lever is made to fit tightly against the end of the rod FQ.

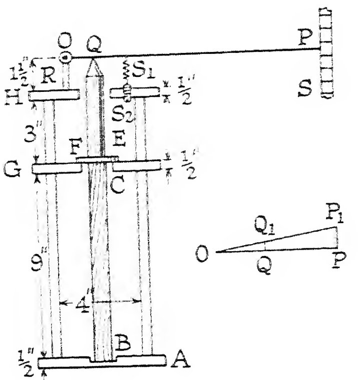


FIG. 152.

EXPANSION DUE TO MOISTURE CONTENT APPARATUS.

To perform an experiment a dried specimen, of suitable dimensions, is placed in position and the screw S_2 is turned until the lever is held tightly against the end of the rod FQ. The apparatus is allowed to stand in an empty vessel and the reading of the end of the lever is noted.

The vessel is now filled with water and the reading of the end of the lever is again noted when the expansion is complete. The change in length QQ_1 is determined from the relation

$$\frac{Q_1Q}{P_1P} = \frac{OQ}{OP}$$

where P_1P, OQ and OP are measurable quantities.

Cohesion

When a piece of chalk is crushed into powder, the forces which hold the particles of the solid together are broken down. These forces are known as cohesive forces and are more pronounced in some solids than in others. Thus the forces of cohesion between the particles of the harder metals are far greater than those between the particles of chalk, salt, etc.

Adhesion

If sand is mixed with lime and water added, a solid mass of mortar is produced when the mixture is left to dry. The lime acts as an adhesive, in so far that it holds the particles of sand together. In wood working the most common adhesive is glue. The holding power of a sample of glue is given in the following table.

TABLE V

Material	Holding Power (lbs. per sq. in.)	
	Cut across the grain	Parallel to the grain
Beech ..	2204	1123
Maple ..	1251	896
Fir	1564	341
Oak ..	1820	782

Ductility

A material is said to possess ductility when a short thick cylinder can be drawn into a long thin wire. Iron and copper are ductile materials.

Malleability

Malleability is that property of a substance which enables it to be hammered out into thin sheets. Copper and gold are malleable substances. In fact, gold is so malleable that it can be hammered out into sheets which are transparent and transmit a green light. The molecules of a malleable substance are loose and the forces of cohesion between

them are small. On the other hand, the molecules of a non-malleable substance are bound together by large cohesive forces.

Excessive hammering of some malleable materials causes them to become hard and brittle. The malleability in these cases can only be restored by re-annealing, i.e., by heating the material to a high temperature and allowing it to cool slowly.

Hardness

Hardness is that property by virtue of which a solid offers resistance to being worn or scratched by another solid. A crude method of comparing the hardnesses of a number of materials is to try the effect of scratching each material with each of the others in turn and arranging them in order of hardness. This method, however, is only qualitative, since it gives the order of hardness and not the relative hardness. Quantitative measurements can be made by means of the following methods.

The Scratch Test

A simple method of determining the hardness of a material is by means of the scratch test. An apparatus, designed by Professor Turner for carrying out this test, is shown in Fig. 153(*a*). AB is a lever pivoted at O. The lever carries a weight W at A and a diamond point is fixed to the upper side of the lever at B. The specimen CD, placed in contact with the diamond point, is moved horizontally and a scratch is made upon its surface. From the figure, it can be seen that the diamond point presses against the specimen with a force equal to $W \frac{OA}{OB}$. The width of the scratch is measured by means of a microscope which possesses a transparent scale in its eyepiece. (N.B.—An account of the microscope may be found in textbooks on Light.) An image of the scratch is brought to a focus on the scale, which is divided into mm. and fractions of a mm. The width of the scratch is then read off directly.

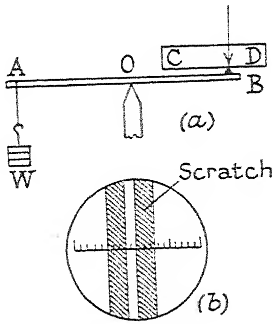


FIG. 153.
TURNER'S APPARATUS FOR HARDNESS TEST.

A second specimen, whose hardness has to be compared with that

of the first specimen, is now placed in position. By trial, the weight W is adjusted so that the width of the scratch is the same as that for the first specimen.

Fig. 153(*b*) shows the images of the two scratches on the transparent scale. When these images have the same width we have:—

$$\frac{\text{Hardness of 1st Specimen}}{\text{Hardness of 2nd Specimen}} = \frac{\text{Force for 1st Specimen}}{\text{Force for 2nd Specimen}}$$

$$= \frac{W_1 \dfrac{OA}{OB}}{W_2 \dfrac{OA}{OB}}$$

$$= \frac{W_1}{W_2}$$

$$= \frac{\text{Wt. for Specimen (1)}}{\text{Wt. for Specimen (2)}}$$

If the hardness of one specimen is known, the hardness of the other specimen can be calculated from the above relation.

The Scleroscope

The hardness of materials may be determined by Shore's scleroscope (Fig. 154), which works on the rebound principle. A small metal cylinder A, with a blunt diamond point, is allowed to fall freely upon the specimen B which rests on the bed C and it is guided in its fall by the glass tube D. The cylinder, on striking the specimen, has acquired kinetic energy which is proportional to v^2, where v is the velocity on impact. Owing to the indentation produced, the cylinder loses some of its energy and the velocity of rebound is less than that of impact. Consequently, the height of rebound is less than the height from which it falls and is measured on a scale attached to the glass tube.

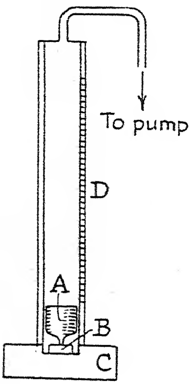


Fig. 154.
SHORE'S SCLEROSCOPE FOR HARDNESS TEST.

For hard materials, the indentation and loss of kinetic energy are small and consequently the height of rebound is considerable. But in the case of softer materials, the indentation and loss of kinetic energy are considerable and the height of rebound is small.

The cylinder is raised to a definite height by

pumping air out of the tube D. Then on allowing the cylinder to fall upon the specimen and measuring the height of rebound, the hardness of the specimen can be determined.

Metal castings have to reach a definite hardness specification and in practice those which do not reach this specification are rejected. One method of conducting the hardness test is to use the scleroscope in conjunction with a selenium (photo-electric) cell. When a beam of light strikes a thin sheet of selenium the electrical resistance of the selenium changes and, if it is in series with a battery and a sensitive ammeter (see Ch. XVI), there is a change of current in the circuit which is shown in the ammeter.

A narrow beam of light which is incident on the selenium cell is arranged at the specified distance above the metal under test and, when the cylinder A rebounds to intercept this beam, an indication is given by the ammeter.

The Brinell Test

In this test, a hardened steel ball (Fig. 155(*a*)) is pressed into the surface of the specimen, with a known steady force. The diameter of the indentation is measured by a micrometer microscope reading to $\frac{1}{20}$ mm. From the diameter, the area of the spherical surface of the indentation is determined. The value of the ratio $\frac{\text{Force}}{\text{Area of Surface}}$ is compared with a table of Brinell numbers, which gives the hardness of the specimen.

The essential parts of the testing machine are shown in Fig. 155(*b*). The machine is based on the hydraulic press principle. The cylinders E and D are filled with oil from a reservoir. B is the plunger, supported by a suitable spring, and the hardened steel ball C is attached to its lower end. (N.B.—The reservoir and the spring which supports the plunger B are not shown in the diagram.) The specimen S, whose hardness is required, is supported on a platform which can be raised until the ball C just touches the upper surface of the specimen. A small plunger A, which moves in the cylinder E, carries a cross bar to

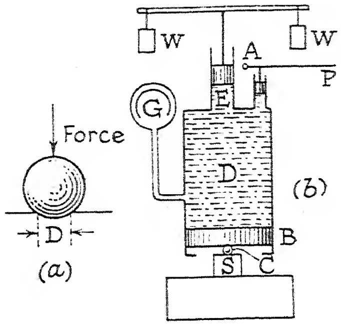


Fig. 155.
BRINELL'S APPARATUS FOR HARDNESS TEST.

which weights WW are attached. This arrangement prevents the fluid pressure from exceeding a definite specified value.

To make a test, the supply of oil from the reservoir is cut off and the specimen is raised into position. The oil is put under pressure by means of a small hand pump P. The plunger A rises in the cylinder E, when the upward thrust of the oil on its lower end overcomes the force with which the plunger is pressed down. At the same time, by the principle of transmissibility of fluid pressure, a large thrust is produced on the plunger B and the steel ball is forced into the specimen. The fluid pressure is given by the gauge G. Thus the thrust on the plunger B, and therefore the downward force on the steel ball, can be calculated.

Exercises XIII

1. How is timber affected by variations in the moisture it contains? How would you determine the amount of moisture in a specimen of unseasoned timber?

(U. L. C. I.; B. S.)

2. Describe how you would determine the amount of moisture in a specimen of unseasoned timber. What results would you expect to obtain (*a*) in this specimen, and (*b*) in a specimen taken from a piece of seasoned timber?

(U. L. C. I.; B. S.)

3. With the aid of sketches and necessary descriptive notes, make clear a suitable design for one of the following:—

(*a*) Apparatus to demonstrate and measure with fair accuracy the expansion and contraction of a metal rod or tube as a result of temperature change.

(*b*) Apparatus to demonstrate changes in dimensions of a wood specimen due to change in moisture content.

(C. G. L. I.; Hand. S.)

4. Describe a way of determining the relative hardness of three specimens of brass.

(C. G. L. I.; Hand. S.)

5. Show how the properties of (*a*) steel, (*b*) lead, (*c*) ash, (*d*) oak, make them useful in the workshop.

(C. G. L. I.; Hand. S.)

CHAPTER XIV

THE CHEMISTRY OF AIR AND ITS CONSTITUENT GASES. WATER AND ITS CONSTITUENTS

Introduction

We have already studied the physical properties of the atmosphere, in which we were concerned with its weight, pressure, etc. We shall now consider the chemical aspects of the air. Is the air one gas or a mixture of gases? If the air is a mixture what are its constituent gases and what are the proportions in which these gases exist? What is the difference between fresh air and the air in a stuffy room and what happens when substances burn? The following experiments will serve to ascertain these points.

Experiment XXXIII

Select a small piece of each of the following metals: copper, lead, zinc, iron, magnesium and aluminium. After cleaning, examine the appearance of each metal.

Heat each metal in turn on the lid of a porcelain crucible, placed on a pipe clay triangle which rests on a tripod. The heating can be performed by means of a bunsen burner. Note the colour and appearance of each after heating. Allow to cool and again note the appearance and colour.

It will be found that all the above metals, with the exception of aluminium, alter in appearance.

Aluminium is very little affected by heating, whereas the other metals are coated with a covering of different colours. In the case of lead melting takes place and a reddish brown tarnish is produced, which on cooling becomes yellow. Magnesium when heated strongly burns with an intense flame and produces a white powder. Zinc and copper do not burst into flame but they are coated with a white and black powder respectively.

Experiment XXXIV

Place pieces of magnesium ribbon in a porcelain crucible provided with a lid and counterpoise on a balance. Now heat the crucible and contents on a pipe clay triangle, leaving a small air space between the

crucible and the lid. Allow the crucible and contents to cool and replace on the balance. An increase in weight is noticed.

From this experiment it can be seen that the metal gains in weight when heated strongly in air.

The Composition of the Air

The air consists mainly of a mixture of two gases, namely oxygen and nitrogen. In addition, there is a small quantity of carbon dioxide and minute traces of the rare gases argon, krypton, neon and xenon. We have seen that magnesium when heated strongly in air gains in weight. This gain in weight is due to the magnesium combining with the oxygen and forming a white powder called magnesium oxide. In the case of the metals treated in Experiment XXXIII, the metals combine with the oxygen of the air, producing metallic oxides, e.g., black copper oxide from copper, white zinc oxide from zinc, etc. The metals are said to be oxidised and the process of combining with oxygen is called oxidation.

Experiment XXXV

To find the percentage composition of the air by volume

Take a uniform glass tube A (Fig. 156), about $1\frac{1}{2}$ cm. in diameter and sealed at one end. Place a small quantity of water in the tube so as to occupy about 1 cm. of its length, close the open end with the thumb and invert the tube with this end under water contained in a trough. Adjust the water levels in the tube and the trough to be the same and measure the length of the air column with a metre stick. Now fit up a small glass container B in a rubber bung C which fits the tube tightly. Place in it a few pieces of solid pyrogallol and 3 to 5 pellets of sodium hydroxide. This is known as alkaline pyrogallol and it readily absorbs oxygen. With the end of the tube still under water, carefully insert the bung and container so as to obtain a tight fit in the tube. Remove the tube from the trough and shake it a few times. The liquid becomes brown. After about 10 minutes, replace the tube with the end containing the bung under the water in the trough. Remove the

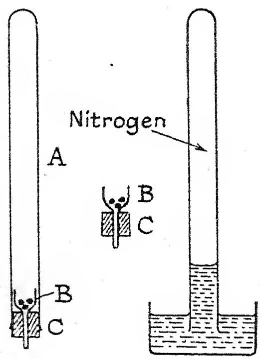


Fig. 156.
PERCENTAGE COMPOSITION OF AIR BY VOLUME.

bung, adjust the water levels to be the same and measure the length of the column of nitrogen remaining. This is found to be $\frac{4}{5}$ of the initial length of the air column.

Experiment XXXVI

Place some iron filings, which have been moistened with water, in a small muslin bag and attach the bag to the end of a piece of copper wire. Place the wire with the bag in a gas jar as shown in Fig. 157. Leave the apparatus for a week or two, and it will be found that the water has risen in the tube, so as to occupy about $\frac{1}{5}$ of its volume. Withdraw the bag and examine the filings. Note that the iron has rusted and that $\frac{1}{5}$ of the volume of the air has disappeared.

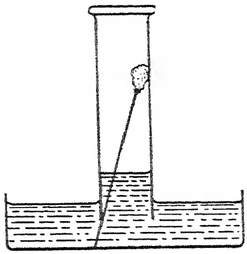


Fig. 157.

RUSTING OF IRON—PERCENTAGE COMPOSITION OF AIR BY VOLUME.

Now remove the jar from the trough and place a burning taper in the jar. The taper is extinguished immediately, showing that the remaining gas does not support combustion.

In this experiment, as in Experiment XXXV, the oxygen of the air representing $\frac{1}{5}$ of its volume is used up, while the remaining $\frac{4}{5}$ of the air is nitrogen which does not support combustion. In the process of rusting, the iron combines with oxygen at ordinary temperatures, forming iron oxide. Rusting is really slow oxidation and takes place only when water is present in addition to the oxygen.

Physical and Chemical Changes

In Ch. XI we saw that ice, water and steam are three states of the same substance. The state is determined by the temperature and the change from one state to another is known as a physical change. In this type of change there is no alteration in the weight of the substance. Another example of a physical change is the expansion of a substance owing to heat.

In the case of the heating of metals in air, when the temperature is high enough, a different substance is formed, viz., lead oxide from lead, magnesium oxide from magnesium, and copper oxide from copper. This type of change is known as a chemical change and it is accompanied by an alteration in the weight of the substance.

Elements

An element is a substance which cannot be decomposed into other substances by chemical processes. There are 92 elements which are generally classified into metals and non-metals.

Metals such as copper, zinc, lead and magnesium are metallic elements. On the other hand, substances such as oxygen, nitrogen, sulphur and carbon are non-metallic elements.

Compounds

In addition to the elements there are substances which are more or less complex. These substances are composed of two or more elements in chemical combination and are known as chemical compounds. Thus magnesium oxide is a chemical compound which is entirely different in properties from either magnesium or oxygen. If magnesium oxide be divided into small particles, each particle still consists of magnesium oxide. If the subdivision be carried out still further, the minute particles still retain the properties of magnesium oxide. The smallest particles into which a substance can be divided, while still retaining its properties, are known as molecules.

The Law of Definite Proportions

If Experiment XXXIV be repeated with different weights of magnesium it will be found that 24 grams of magnesium, when completely oxidised, produce 40 grams of magnesium oxide and 12 grams of magnesium produce 20 grams of magnesium oxide, and so on. That is, 24 grams of magnesium combine with 16 grams of oxygen; 12 grams of magnesium combine with 8 grams of oxygen, etc. The ratio of oxygen to magnesium is 16 to 24, 8 to 12, i.e., 2 to 3 or 40 per cent. by weight of oxygen to 60 per cent. by weight of magnesium. *Thus the ratio by weight in which elements combine chemically to form a definite chemical compound is always the same.*

The Law of Multiple Proportions

If we consider the case of the oxidation of lead, for instance, under certain conditions one type of oxide is formed, and under other conditions another type of oxide is formed. Thus in the one case 207 grams of lead combine with 16 grams of oxygen to form 223 grams of lead oxide, while in the other case 207 grams of lead combine with 32 grams of oxygen to form 239 grams of lead dioxide. The ratio by weight in which the oxygen combines with the same weight of lead in the two

cases is as 2 to 1. This leads us to the law of multiple proportions which states that *if an element combines with another element to form more than one chemical compound the weights of the one which combine with a fixed weight of the other bear a simple relation to one another.*

Mixtures

Sand and sugar form a mixture which may be separated by mechanical means. When sand and sugar are mixed and shaken up with water, the sugar dissolves and the sand remains at the bottom of the vessel. The sand may be separated from the sugar solution by a process known as filtration and the sugar may be regained by evaporating the water.

The percentage composition of a mixture varies according to the quantities of the constituents present. In a chemical compound, however, the percentage composition is always the same.

Preparation of Oxygen

Experiment XXXVII

Heat strongly a little mercuric oxide in an ignition tube and place a glowing splint in the mouth of the tube. The splint bursts into flame and globules of mercury are left at the top of the tube owing to the distillation of the mercury.

Experiment XXXVIII

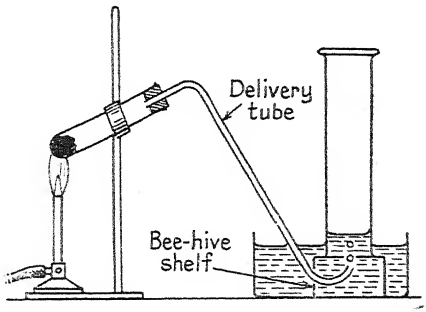


Fig. 158.
PREPARATION OF OXYGEN.

Assemble the apparatus shown in Fig. 158 and place a mixture of ten parts by weight of potassium chlorate and one part by weight of manganese dioxide in the test tube. Wrap a piece of iron gauze round the tube and play upon it with a bunsen flame.

Oxygen is driven off and is collected by the downward displacement of water. (The first jar will contain a quantity of air. Why ?) Disconnect the delivery tube from the test tube, in order to prevent water from being drawn into the tube as it cools.

The presence of the manganese dioxide merely alters the rate at which the oxygen is given off. Substances which alter the rate at which a chemical change takes place are called catalysts and are unaffected at the end of the reaction.

Experiment XXXIX

Collect several jars of oxygen and burn a little sulphur in a deflagrating spoon. Note that the sulphur burns in air. Now introduce the burning sulphur (in the spoon) into a jar containing oxygen.

The sulphur burns more readily with an intense blue flame and the product of combustion is a gas known as oxide of sulphur (sulphur dioxide).

Experiment XL

Repeat the previous experiment with charcoal. The charcoal glows more readily in oxygen than in air, the product of combustion in this case being oxide of carbon (carbon dioxide).

Experiment XLI

Introduce a piece of burning magnesium into a jar containing oxygen, by means of a pair of crucible tongs. The magnesium burns with a far more intense light than before. A white powder is found on the sides and bottom of the jar. This powder is known as magnesium oxide.

The Properties of Oxygen

Oxygen is a colourless, odourless gas which is only slightly soluble in water. Thus oxygen can be collected by the downward displacement of water. The experiments outlined above show that oxygen does not burn and that it supports burning to a greater extent than air. When elements combine with oxygen they form oxides.

Oxygen in Industry

Very high temperatures are required for the oxidation of metals, although in the case of the rusting of iron the oxidation takes place at ordinary temperatures. The heat which is required to produce the oxidation is known as heat of combustion.

The Structure of the Bunsen Flame

When a bunsen burner is lit with the holes at the bottom open, air is drawn through them and the flame is nearly invisible. When the holes are partly closed the flame becomes more luminous. There are two distinct portions of the flame, an inner cone A which consists of unburnt gas (hydrocarbons, hydrogen, etc.) and an outer envelope B in which the gas is burning, i.e., combining with the oxygen of the air (Fig. 159(*a*)). The outer envelope is at a very high temperature, the point just to one side of the tip being the hottest portion. This outer envelope is the oxidising flame, and by placing certain metals in it they are oxidised. The inner cone is relatively cooler.

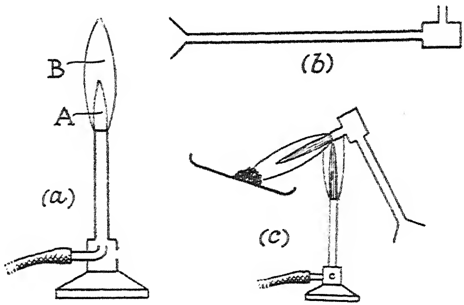


Fig. 159.

(*a*) STRUCTURE OF A BUNSEN FLAME, (*b*) BLOWPIPE, (*c*) OXIDATION BY BLOWPIPE.

The Blowpipe

Fig. 159(*b*) shows a blowpipe which is used in the oxidation of metals. The metal is placed on a piece of porcelain and the luminous bunsen flame is directed by the blowpipe so that the tip of the outer envelope is in contact with the metal (Fig. 159(*c*)).

The metal is oxidised and it is often possible to detect the metal from the colour of its oxide.

The Oxy-acetylene Flame—Welding

The heat evolved when hydrogen or acetylene gas burns in oxygen is very intense and is utilised in industry in many ways. Fig. 160(*a*) shows a blowpipe used in oxy-acetylene welding. Acetylene under pressure is forced through the tube A and is lit at the jet B. Oxygen under pressure is sent through the tube C and the acetylene flame increases in intensity. The pressures of the two gases are adjusted until the flame is thin and straight, when it gives out intense heat.

The structure of the oxy-acetylene flame is shown in Fig. 160(*b*).

There are four zones: (1) the zone of no combustion in which the oxygen and the acetylene are approximately at air temperature, (2) the bluish white zone in which the acetylene combines with the oxygen, (3) the blue zone in which very little combustion takes place, and (4) the orange red zone in which the products of combustion of the second zone combine with the oxygen of the air. The hottest part of the flame is at the point X, just outside the second zone.

In welding two pieces of iron together, a rod of suitable material is placed between the faces to be joined. After adjusting the flame to the neutral state in which there is neither excess of oxygen nor of acetylene, the flame is passed round the rod in circular fashion. The hottest part of the flame is used and the radiant heat from it is then sufficient to

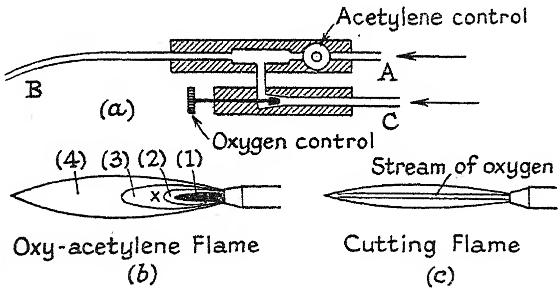


FIG. 160.

(*a*) OXY-ACETYLENE TORCH, (*b*) STRUCTURE OF THE OXY-ACETYLENE FLAME, (*c*) CUTTING FLAME.

melt the rod and the two faces to be joined. In these circumstances oxide is produced. The oxide floats away and may be removed when cold by grinding or machining.

Many metals can be cut by adding a stream of oxygen under high pressure to the oxy-acetylene flame. The stream of oxygen, passing through the flame, is shown in Fig. 160(*c*). When the metal has been raised to its ignition temperature by the flame, combustion takes place at the point at which the stream of oxygen strikes the metal. The metal is oxidised along a narrow slit and the metallic oxide, having a lower melting point than the metal, is driven out of the slit by the cutting jet.

NITROGEN

We have seen that when all the oxygen in a jar of air has been used up by the combustion of a substance, the gas which remains is nitrogen.

If a glowing splint be placed in a jar of nitrogen, it will be extin-

guished immediately, showing that nitrogen does not support combustion. Nitrogen is an inert gas and will not combine with oxygen, unless the temperature is very high. Thus small quantities of a gaseous compound consisting of nitrogen and oxygen are produced during lightning flashes or near the spark gap, during an electric discharge. Nitrogen does not support respiration, and yet it is not poisonous. In the air it serves as a diluent for the oxygen.

Other Constituents of the Air—Carbon Dioxide

Experiment XLII

Draw air through lime water contained in a bottle B, by running water out of an aspirator A (Fig. 161). The lime water, which is a clear solution of calcium hydroxide in water, assumes a milky appearance.

Neither oxygen, nitrogen nor a mixture of these two elements will produce this effect. Thus there appears to be another constituent of the air, which has the property of turning lime water milky. This gaseous substance is called carbon dioxide.

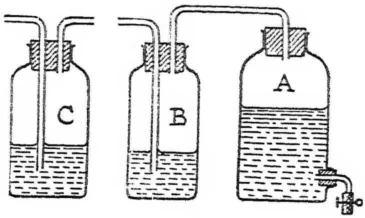


Fig. 161.

APPARATUS FOR SHOWING THE PRESENCE OF CARBON DIOXIDE IN THE ATMOSPHERE.

Experiment XLIII

Assemble the apparatus (Fig. 161), having placed fresh lime water in B and refilled the aspirator A with water. Connect the bottle C, which contains a solution of caustic soda, to the bottle B. Draw air through the bottles by running water from the aspirator. The lime water in B is unaffected.

Evidently the constituent of the air which has the property of turning lime water milky has been removed by the caustic soda solution.

Experiment XLIV

Draw air through a solution of caustic soda as in Experiment XLIII. The lime water in B is unaffected. Now disconnect the stopper from the bottle B and introduce a lighted wooden splint. On withdrawing the splint, replacing the stopper and shaking the bottle, the lime water assumes a milky appearance.

Now the air drawn through the bottle B was free from carbon dioxide.

But when a piece of wood was burned in this air, a gas was produced which turned lime water milky. The chief constituent of wood is carbon and thus the burning of wood produces carbon dioxide. The burning of other substances containing carbon also produces carbon dioxide.

Preparation and Properties of Carbon Dioxide

When dilute hydrochloric acid is poured down the thistle funnel C into the vessel A which contains marble chips (a form of calcium carbonate), effervescence takes place and carbon dioxide gas is given off (Fig. 162). The carbon dioxide passes through the bent tube into the gas jar B and the marble is converted into calcium chloride. The chemical reaction is represented as follows:—

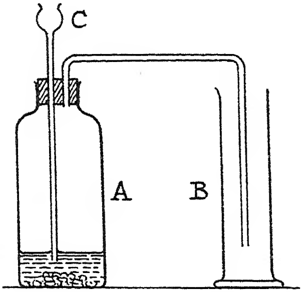


Fig. 162.
PREPARATION OF CARBON DIOXIDE.

Calcium Carbonate (marble) + Hydrogen chloride (hydrochloric acid) = Calcium chloride + Carbon dioxide + Hydrogen oxide (water)

Carbon dioxide is a colourless, odourless gas which is not very active, as it neither burns nor supports burning. Carbon dioxide is very soluble in water and for this reason it is not usually collected by the downward displacement of water. Being heavier than air, when carbon dioxide is prepared it is collected by the upward displacement of air. As we have seen, carbon dioxide turns lime water milky and this is the chief test for the gas.

Respiration

Experiment XLIV shows that the burning of substances, containing carbon, produces carbon dioxide. This gas is also produced during the process of respiration. Air is taken in by the lungs and some of the oxygen is converted into carbon dioxide. Hence it might be imagined that the quantity of oxygen in the air would diminish and the quantity of carbon dioxide increase. This is not the case, however, for the quantity of carbon dioxide in the air remains practically fixed (0·04 per

cent by weight) and varies very slightly from place to place. The air in industrial districts contains slightly more carbon dioxide than the air in country districts, and the reason for this is not far to seek. We shall now see why the percentage of carbon dioxide in the air is practically constant.

Experiment XLV

Pass carbon dioxide for a considerable time into a quantity of water, contained in a trough. Bubbles of carbon dioxide escape into the air but a quantity dissolves in the water. Now place a small plant in the trough and place an inverted funnel over it. Support a test tube filled with water over the funnel (Fig. 163) and allow the apparatus to stand for a few days in the sunlight. A gas collects in the upper part of the test tube and, when this gas is examined with a glowing splint, it is found to be oxygen.

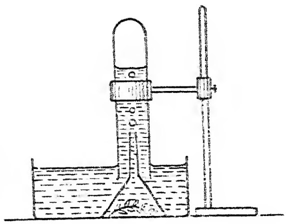


Fig. 163.
EFFECT OF SUNLIGHT ON GREEN PLANTS.

We have seen that animals in the process of respiration take in air and convert some of the oxygen into carbon dioxide. Plants also carry on respiration day and night, i.e., they absorb oxygen, but at a rate which is much slower than that of animals. Green plants carry on a process known as photo-synthesis (i.e., light building) in the hours of sunlight in which carbon dioxide is absorbed. This process of photo-synthesis is rapid when light and temperature are suitable and the sum total of the two effects in daylight results in plants absorbing carbon dioxide and giving out oxygen. Hence the balance of nature keeps the percentage of carbon dioxide in the air constant.

Water Vapour

Another constituent of the air is water vapour, the quantity of which varies from place to place. Water vapour is continually produced by the process of evaporation, and this is balanced by condensation which shows itself in the deposition of dew and the falling of rain, snow, etc

Air as a Mixture

It has already been seen that $\frac{1}{5}$ of the volume of air consists of oxygen. Since oxygen is more soluble in water than nitrogen, the air driven off when water (saturated with air) is heated contains about $\frac{1}{3}$ of its volume

of oxygen. Thus air is a mixture, since its percentage composition can be made to vary to a considerable extent by physical processes. On the other hand, water, which will now be studied, is a chemical compound with a definite and constant composition.

Water and its Constituents

The Properties of Water

Some of the properties of water are well known. Pure water is tasteless, colourless and odourless. Its freezing point and boiling point are 0°C and 100°C respectively under a pressure of 760 mm. of mercury. One of the most important properties of water is its power to extinguish flame. This is due to the fact that a burning substance requires oxygen for its combustion. Thus when water is poured on burning wood, the surface of the wood has no access to the oxygen of the air and burning ceases.

Water in large quantities can easily be detected, but when in very small quantities its detection can be effected by its action on anhydrous copper sulphate. This substance is a white powder which turns blue when brought into contact with water.

Water as a Solvent

A solution is formed when soluble substances called solutes, which can be solids, liquids or gases, dissolve in suitable solvents of which water is the most common. Some substances when dissolved in water give liquids quite different in colour from the substances dissolved, whereas other substances do not dissolve in water. If a small quantity of a substance is dissolved in a large quantity of water, the substance distributes itself uniformly throughout the water. Thus if the smallest particle of potassium permanganate is placed in a vessel containing water and left for a time, the particle goes into solution and the liquid assumes a uniform pinkish colour. If more water is added, the dissolved solid spreads itself out and assumes another uniform distribution. The solution is said to be diluted and theoretically there is no limit to this dilution.

If a large quantity of potassium permanganate is added to a limited quantity of water, some of the solid dissolves and the excess remains in contact with the solution. The solution is said to be saturated at the given temperature.

If the temperature is increased more potassium permanganate dis-

solves, until saturation point is again reached for the particular temperature.

When a solution of non-volatile solid (i.e., a solid which does not vaporise) is boiled, the water is driven off in the form of steam. If the boiling is continued until all the water disappears, the solid is left behind in the vessel.

Water of Crystallisation

When a hot saturated solution of a salt (see Ch. XV) is cooled, some of the salt separates out in a definite crystalline form. Thus when a hot saturated solution of alum is allowed to cool, crystals of a definite shape are produced. Similarly, when a hot saturated solution of blue vitriol (copper sulphate) is cooled rapidly, crystals of a blue colour separate out. A few of these crystals, placed on a watch glass and examined under a microscope, appear to have a definite shape with flat regular faces. A small crystal of copper sulphate, placed in a saturated solution of the same salt and left for a considerable time, grows into a large crystal of the same shape. When a large crystal is broken with a penknife, cleavage takes place and the pieces still retain their faces quite flat and regular.

Crystals of copper sulphate, alum, etc., all contain water, yet feel quite dry to the touch. When these crystals are heated in a test tube water collects on the colder portions of the tube, and if a sufficient quantity be treated the water can be collected. In the case of copper sulphate, a white amorphous powder known as anhydrous copper sulphate is left. If a little water be added, the powder again becomes blue and crystallisation again takes place. The water is in chemical combination with the salt and is known as water of crystallisation.

Some substances, e.g., washing soda, when exposed to the air lose their water of crystallisation and are called efflorescent substances. Other substances such as calcium chloride gain water from the air and ultimately form a solution. Such substances are said to be deliquescent.

Crystallisation from the Melt

Crystals are also formed when molten metal is allowed to cool. The molten metal or melt as it is called solidifies and acquires a definite crystalline structure which is often seen in a piece of newly broken iron.

When two metals are melted together in suitable proportions to form an alloy, the particles of one metal assume a uniform distribution among the particles of the other and a homogeneous solution is produced. The metal in excess is called the solvent and the other the solute. When such a solution is cooled, in certain cases it forms what is known as a solid

solution and the crystalline structure of the alloy is far different from that of either of the constituents. Thus carbon, nickel, tungsten, manganese, etc., in solution with iron produce steels of different varieties, with different crystalline structures.

The rate of cooling of the solid solution from the melt also affects the crystalline structure. When a solid solution just under melting point is suddenly cooled, i.e., quenched, the structure is far different from that produced when the solution is cooled slowly. The sudden cooling keeps the arrangement of the particles very nearly the same at low temperatures as at high temperatures. But if the solid solution is cooled slowly, as in annealing, the arrangement of the particles continually changes as the temperature falls. Thus steel which has been quenched has its crystalline structure altered by tempering, that is, by reheating the steel to about 200°C or 300°C and then allowing it to cool slowly.

Experiment XLVI

Analysis of Water by passing steam over red-hot iron

Set up the apparatus shown in Fig. 164. A is a flask containing water. This flask is fitted with a rubber stopper through which pass the delivery tube B and the safety tube C. D is an iron tube, supported in a furnace. The tube contains a quantity of iron nails. An inverted gas jar E, filled with water, stands on a beehive shelf in a trough containing water.

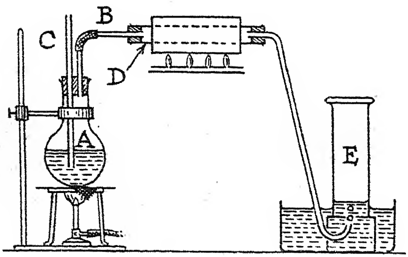


Fig. 164.

PREPARATION OF HYDROGEN BY PASSING STEAM OVER RED-HOT IRON.

Pass steam over the red-hot iron and allow the gas evolved, together with the air in the apparatus, to escape for a time. When all the air has been displaced from the apparatus, collect the gas evolved in a gas jar and apply a lighted splint to the mouth of the jar. If the experiment is satisfactorily performed the collected gas will burn with a bluish flame.

The heated iron acts on the steam and a gas, known as hydrogen, is evolved. The other constituent of the steam, known as oxygen, combines with the heated iron, forming iron oxide.

The chemical reaction is:—

Iron + Hydrogen Oxide (i.e., water) = Iron oxide + Hydrogen.

Hydrogen is the lightest gas known. When a jar containing hydrogen is closed with a glass plate and an inverted jar containing air is placed above it, on removing the plate the hydrogen rises from the lower to the upper vessel, displacing the air in the process. Hydrogen and oxygen can exist together at ordinary temperatures without chemical combination taking place. It is only when ignited that the gases combine and then the hydrogen burns with a bluish flame. When hydrogen and oxygen are mixed together in the proportion of 2 to 1 by volume and an electric discharge is passed through the mixture, the temperature developed by the electric discharge is sufficient to produce chemical action between them and an explosion takes place. The product of the chemical reaction shrinks to an insignificant volume, viz., the volume of the water produced. If, however, the hydrogen or the oxygen is in excess of this proportion, some hydrogen or oxygen will remain with the water. Thus the volumes in which hydrogen and oxygen combine are in the ratio of 2 to 1.

Exercises XIV

1. What causes iron to rust? A few iron nails were placed in a flask half full of distilled water, which was then boiled for several minutes. The flask was then well sealed and left unopened for several years. The nails were still bright, no sign of rust being noticed. Give some reason for this and describe the methods commonly adopted for preventing the rusting of iron.

(C. G. L. I.; Hand. S.)

2. How would you attempt to determine experimentally the percentage of oxygen (by volume) in ordinary air? Describe the apparatus used.

(C. G. L. I.; Hand. S.)

3. Illustrate, by means of two suitable examples in each case, the difference between

(*a*) Physical change and chemical change.
(*b*) A mechanical mixture and a chemical compound.
(*c*) Metals and non-metals.

(C. G. L. I. ; Hand. S.)

4. What are the main sources of carbon dioxide present in the air, and what are the properties of the gas?

How, in what conditions, and for what purpose, do plants make use of it?

(C. G. L. I.; Hand. S.)

5. Suggest four simple experiments which will lead to an understanding of the conditions favourable to the rusting of iron. State the purpose of each experiment. Describe and explain two ways of preventing the rusting of iron plate.

(C. G. L. I.; Hand. S.)

6. Describe and explain two useful and two objectionable effects of oxidation likely to occur in a workshop.

(C. G. L. I.; Hand. S.; part question.)

7. Describe a method of tempering steel, and explain the effect on the structure of the metal.

(C. G. L. I.; Hand. S.)

8. Describe one method by which carbon dioxide may be prepared in small quantities, giving the equation of the reaction involved. What are the properties and uses of carbon dioxide ?

(C. G. L. I.; Hand. S.)

9. What is meant by " oxidation," and what is its effect in the case of (*a*) iron, (*b*) copper, and (*c*) magnesium ?

(C. G. L. I.; Hand. S.)

10. Describe an experiment by which the composition of water might be determined.

(C. G. L. I.; Hand. S.)

CHAPTER XV

ACIDS, SALTS AND REDUCTION

ACID FORMING OXIDES

When a little sulphur is heated in a deflagrating spoon until it burns and the spoon is inserted in a jar containing oxygen, the sulphur continues to burn with an intense blue flame and a gas known as sulphur dioxide is produced. When the products of combustion are shaken up with water and a little blue litmus solution is added, the litmus solution turns a red or purple colour. Now blue litmus is a dye and in solution it assumes a red colour in the presence of an acid. Thus when the gas sulphur dioxide is dissolved in water an acid is formed. This acid is known as sulphurous acid and the chemical reactions in its formation are:—

Sulphur	+	Oxygen	=	Sulphur dioxide.
Sulphur dioxide	+	Hydrogen oxide (Water)	=	Hydrogen sulphite. (Sulphurous acid)

Under certain conditions when sulphur combines with oxygen, sulphur trioxide is produced, and when this oxide is dissolved in water an acid known as sulphuric acid is formed, viz.:—

Sulphur trioxide	+	Hydrogen oxide (Water)	=	Hydrogen sulphate. (Sulphuric acid)

When a piece of charcoal is burned in a jar of oxygen, carbon dioxide gas is produced. When the carbon dioxide is shaken up with water and a little blue litmus solution is added, the litmus solution is turned red. An acid known as carbonic acid is produced and the chemical reactions are shown below:—

Carbon	+	Oxygen	=	Carbon Dioxide.
Carbon dioxide	+	Hydrogen oxide (Water)	=	Hydrogen carbonate. (Carbonic acid)

An acid, viz., nitric acid, is also produced when the oxide of nitrogen, known as nitrogen pentoxide, is dissolved in water. The chemical reaction is as follows:—

Nitrogen pentoxide	+	Hydrogen oxide (Water)	=	Hydrogen nitrate. (Nitric acid)

Now sulphur, carbon and nitrogen are non-metals and when burned

in oxygen they form non-metallic oxides. In general non-metallic oxides dissolved in water produce acids which turn blue litmus solution red.

i.e., Non-metallic oxide + Water = Acid.

In each of the cases considered the acid produced contains the element hydrogen, and as a matter of fact hydrogen is a constituent of all acids.

Basic Oxides and Alkalis

When a little metallic sodium is burned in an evaporating dish, sodium oxide is produced. This oxide, dissolved in water, produces a solution of sodium hydroxide (i.e., caustic soda) and the solution appears rather greasy to the touch. When a little red litmus solution is added, the litmus turns a blue colour. The chemical reactions in the formation of sodium hydroxide are shown below:—

Sodium + Oxygen = Sodium oxide.

Sodium oxide + Hydrogen oxide (Water) = Sodium hydroxide. (Caustic soda)

Similarly, when the metallic oxide, calcium oxide (lime), is dissolved in water, calcium hydroxide solution is produced and this solution turns red litmus solution blue. Now red litmus solution becoming blue is a test indicating the presence of an alkali, and evidently both sodium and calcium hydroxides are alkalis.

Metallic oxides are known as bases. Some bases are insoluble in water, while those like calcium, potassium and sodium oxides dissolve in water forming alkalis.

Formation of Salts

Experiment XLVII

Pour a quantity of dilute sulphuric acid into an evaporating dish and add a little red litmus solution. Now run caustic soda solution into the acid, drop by drop, from a burette. A stage is reached when the red litmus solution just begins to turn a blue colour. The acid has been neutralised by the alkali and the slight excess of alkali turns the red litmus solution blue. The solution is now neutral, that is, it is neither acid nor alkaline. When the dish is heated strongly water is driven off and ultimately a dry powder is left. This powder is sodium sulphate and the chemical reaction is:—

Hydrogen sulphate (Sulphuric acid) + Sodium hydroxide (Caustic soda) = Sodium sulphate + Hydrogen oxide (water)

Experiment XLVIII

Pour a quantity of caustic soda solution into an evaporating dish and add a drop or two of blue litmus solution. Sodium hydroxide is an alkali and has no effect on blue litmus. Now run dilute hydrochloric acid into the dish from a burette, a drop at a time, until the blue litmus solution just begins to turn red. The caustic soda solution is neutralised and the extra drop of acid turns the blue litmus solution red. Evaporate the residue to dryness and a substance which tastes like common salt is left.

The chemical reaction is represented thus:—

Sodium hydroxide +	Hydrogen chloride =	Sodium chloride +	
(Caustic soda)	(Hydrochloric acid)	(Common salt)	[Hydrogen oxide (water)]

When an acid is neutralised by an alkali, a salt and water are produced, viz.:—

Acid + Alkali = Salt + Water.

The salt is generally neutral and has no effect on either blue or red litmus solution. Sulphuric, hydrochloric, nitric and carbonic acids when neutralised by an alkali give salts called sulphates, chlorides, nitrates and carbonates respectively.

Experiment XLIX

Pour a little dilute sulphuric acid into a porcelain dish and warm it. Now add a small quantity of black copper oxide until no more dissolves. Then filter off the liquid into another evaporating dish, evaporate the liquid to a small volume and allow it to cool. Crystals of copper sulphate separate out. The chemical reaction is as follows:—

Copper oxide +	Hydrogen sulphate =	Copper +	Hydrogen oxide
	(Sulphuric acid)	sulphate	(Water)

Thus: Basic oxide + Acid = Salt + Water

Production of Salts by the Action of Acids on Metals

When dilute sulphuric acid is poured upon granulated zinc, the zinc disappears, hydrogen gas is given off and a salt known as zinc sulphate is formed, viz.:—

Zinc + Hydrogen sulphate = Zinc sulphate + Hydrogen

We may summarise the results on salt formation as follows: (1) An acid contains the element hydrogen; (2) an alkali contains a metallic element; (3) a salt is neutral; (4) when an acid is neutralised by a basic oxide or an alkali, the hydrogen and the metallic element exchange places; (5) the substance formed by substituting hydrogen for the metal in a basic oxide or an alkali is water. There are one or two important exceptions to (3).

Reduction

A reducing agent is a substance which withdraws oxygen from another substance in the course of a chemical change. The process is known as reduction and the chief reducing agents are hydrogen, carbon monoxide, carbon and coal gas.

A wide glass tube C (Fig. 165(*a*)), provided with corks through which the glass tubes A and B pass, contains a quantity of red lead oxide. Coal gas is passed through the tube A and the gas is lit at the jet B. When the lead oxide is strongly heated by means of a bunsen burner metallic lead appears. Nearly all the constituents of the coal gas, including hydrogen, combine with the oxygen of the lead oxide which is reduced to metallic lead. In the case of the hydrogen the chemical reaction is as follows:—

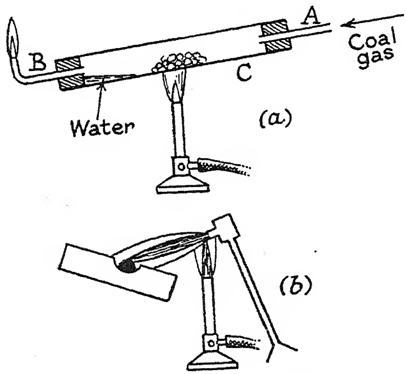


FIG. 165.
(*a*) REDUCTION OF RED LEAD OXIDE BY COAL GAS, (*b*) REDUCTION OF METALLIC OXIDES BY BLOWPIPE FLAME.

$$\text{Lead oxide} + \text{Hydrogen} = \text{Lead} + \text{Hydrogen oxide (water)}$$

Many metallic oxides can be reduced to the metal by placing the oxide in a small hole in a piece of charcoal (Fig. 165(*b*)) and using a blowpipe flame upon it, taking care to use a luminous bunsen flame and to allow the top of the central zone to play upon the oxide. The central zone contains the unburnt hydrogen and hydrocarbons which reduce the metallic oxide to the metal.

Carbon Monoxide

When carbon dioxide is passed over red-hot carbon, the carbon dioxide is reduced to carbon monoxide. The red hot carbon and the carbon in the dioxide share the oxygen and form a lower oxide of carbon as shown below:—

Carbon + Carbon dioxide = Carbon monoxide

When carbon burns in a plentiful supply of oxygen the higher oxide, carbon dioxide, is produced, but if the quantity of oxygen is limited carbon monoxide is formed.

Carbon monoxide burns with a bluish flame, combining with the oxygen of the air to form carbon dioxide, viz.:—

Carbon monoxide + Oxygen = Carbon dioxide

This property of being able to combine readily with oxygen makes carbon monoxide a good reducing agent and it is used in industry for reducing iron ore to metallic iron in blast furnaces.

Producer Gas

When air is passed over red-hot coke, which is a form of carbon, the carbon combines with the oxygen of the air and two gaseous products are formed, carbon monoxide and nitrogen, viz.:—

$$\underbrace{\text{Oxygen} + \text{Nitrogen}}_{\text{(air)}} + \underbrace{\text{Carbon}}_{\text{(coke)}} = \text{Carbon monoxide} + \text{Nitrogen}$$

Carbon monoxide and nitrogen constitute simple producer gas. Since carbon monoxide burns in air, producer gas serves as a fuel and it is used for heating the retorts in coal gas manufacture.

Water Gas

When steam is blown over red-hot coke, the coke combines with the oxygen of the steam and carbon monoxide and hydrogen are produced, viz.:—

$$\underset{\text{(water)}}{\text{Hydrogen oxide}} + \underset{\text{(coke)}}{\text{Carbon}} = \text{Carbon monoxide} + \text{Hydrogen}$$

This mixture of carbon monoxide and hydrogen is known as water gas and both the constituents burn readily in air.

In the manufacture of water gas, air is first blown over red-hot coke until the coke becomes excessively hot. Steam is then blown over the

red-hot coke until it is so far cooled that decomposition nearly ceases. The steam is then shut off and air is again passed over the coke until it again becomes red hot. The alternate passing of air and steam is thus continued.

Since carbon monoxide and hydrogen readily combine with oxygen, water gas is a good reducing agent. When enriched with gaseous hydrocarbons, water gas also serves as an illuminating gas.

Coal Gas

Coal gas is produced by the destructive distillation or the carbonisation of coal. Coal gas consists almost entirely of combustible gases, many of which are highly luminous. The chief illuminating constituent is ethylene, but it is mixed with other gaseous hydrocarbons, e.g., olefines and acetylene, along with carbon monoxide, hydrogen and a small amount of nitrogen. In the distillation of coal very important by-products are formed. These include liquid hydrocarbons, known as coal tar, gaseous and liquid compounds of sulphur, namely sulphuretted hydrogen and carbon disulphide, and ammoniacal liquor.

The coal is heated in retorts which consist of large closed chambers made of silica or fire brick. Producer gas serves as the fuel and a temperature of 1,000°C is attained. There are two types of retort, the vertical and the horizontal types. In the vertical type, coal is added at the top and passes slowly down the retort. During its downward passage, the coal is carbonised and withdrawn as coke at the bottom. The crude gas is led away through a pipe into the main pipe which is also fed from other retorts. As the crude gas leaves the main pipe, it is cooled in a condenser where coal tar and ammoniacal liquor condense. The tar and liquor are run off into underground tanks and separated later. The gas then passes through a pumping house where pumps known as extractors accelerate the passage of the gas from the retorts to the holder. The gas is further treated to eliminate the remaining tar and ammonia and, to eliminate the sulphur compounds, it is passed over beds of iron oxide. The gas is then passed over activated carbon to remove the benzol. Naphthalene is removed at the same time and finally the gas is passed into the holder.

The Smelting of Iron Ore

The reducing property of carbon monoxide is utilised in the smelting of iron ore in blast furnaces. The iron ore is generally found in clay ironstone and it is first calcined by stacking it with fuel in shallow kilns

and carefully regulating the temperature and the air supply so that the moisture, carbon dioxide, sulphur and arsenic are first expelled. The ferrous oxide which constitutes the ore is oxidised to ferric oxide and the ore becomes more porous. These factors help in the final reduction of the oxide to metallic iron.

The smelting takes place in a furnace charged with the calcined ironstone, limestone and coke in certain proportions. Air is introduced under high presssure at openings near the bottom of the furnace, and the temperature is maintained at about 2,000°C (white heat).

A simple explanation of the chemical reactions is as follows. The quantity of air admitted is insufficient for the complete combustion of the coke (carbon) and under these conditions carbon monoxide is produced, viz.:—

Carbon +	Oxygen	=	Carbon monoxide
(coke)	(limited supply)		(gas)

The temperature of the materials gradually rises as they descend the furnace. At a certain point, a temperature is reached at which the ascending carbon monoxide reduces the ferric oxide to metallic iron and the following chemical reaction takes place:—

Ferric oxide + Carbon monoxide = Iron + Carbon dioxide

The molten iron collects in the base or the hearth of the furnace; the slag is drawn off through a channel near the base and the gases pass out through a pipe near the top of the furnace.

Exercises XV

1. Explain the meanings of (*a*) acidic oxide, (*b*) basic oxide, (*c*) alkali, (*d*) acid. Give one example of each, and state briefly how it may be obtained.

(C. G. L. I.; Hand. S.)

2. What happens when steam is passed over (*a*) heated iron filings, (*b*) red-hot coke ? Describe briefly one industrial use of each reaction.

(C. G. L. I.; Hand. S.)

3. Give with a short explanation in each case, two examples of (*a*) analysis, (*b*) synthesis, (*c*) double decomposition.

(C. G. L. I.; Hand. S.)

4. Explain the production of three of the following:—

(*a*) Carbon monoxide in a coke-fired stove.

(*b*) Water when wood shavings burn in air.

(*c*) A white deposit when hard water is boiled.
(*d*) A scum when lead is heated in air.
(*e*) Zinc chloride when hydrochloric acid acts on zinc.

(C. G. L. I.; Hand. S.)

5. Describe carefully how to prepare:—

(*a*) Common salt from soda.
(*b*) Lead from litharge.
(*c*) Solid zinc chloride from zinc oxide.
(*d*) Dilute sulphuric acid from the strong acid.

(C. G. L. I.; Hand. S.)

6. Write a short account of the production of producer gas, indicating its composition and its uses.

(C. G. L. I.; Hand. S.)

CHAPTER XVI

THE ELECTRIC CIRCUIT

In these days of wireless, nearly every student is familiar with some of the simple electrical appliances, such as accumulators, terminals, plug keys, etc., which are in everyday use. A few details with regard to the use of these appliances will now be given, their main treatment being left to a later stage.

Conductors and Insulators

It is essential in the first place to understand the difference between a conductor of electricity and an insulator. Substances which allow an electric current to flow through them, with little resistance to the current, are known as conductors, of which copper, silver, mercury, etc., are examples. Substances which allow an electric current to flow through them with great difficulty, by offering a great resistance to the current, are known as insulators. Ebonite, wood, rubber, amber, bakelite, etc., are examples of insulators. Bakelite especially, is used in electric fittings for insulation purposes.

The Accumulator

The accumulator possesses two terminals, a positive and a negative. An electric current leaves the accumulator at the positive terminal and, after passing through the various wires, coils, etc., returns to the negative terminal. In circuit diagrams, accumulators, as well as all types of cell, are represented by a long thin line and short thick line which represent the positive and negative terminals respectively (Fig. 166).

Fig. 166.
CELL.

The Ammeter

Since it is essential to be able to measure the strength of the current taken from an accumulator, the current must pass through some instrument which registers current strength. This instrument is known as an ammeter and carries a scale which is marked 0—1, 0—5 amperes,* etc., according to the

Fig. 167.
AMMETER.

* The ampere is the unit of current strength.

current strength it is designed to measure. The current enters at the positive and leaves at the negative terminal. Fig. 167 shows how the ammeter is represented in a circuit diagram.

The Plug Key

Fig. 168.
PLUG KEY.

The plug key, when inserted in an electric circuit, supplies a ready means of completing or breaking the circuit. Fig. 168 shows how the plug key is represented in a circuit diagram.

The Variable Resistance

Any wire or coil of wire offers a resistance to the passage of an electric current. A long piece of wire offers a greater resistance to the passage of the current than a short piece of the same diameter and

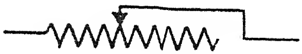


Fig. 169.
VARIABLE RESISTANCE.

Fig. 170.
FIXED RESISTANCE.

material. Also a thin piece of wire offers a greater resistance than a thick piece of the same length and material.

A variable resistance is shown diagrammatically in Fig. 169. If the current is flowing from left to right, it leaves the coil by the slider. Thus, by moving the slider various lengths of the wire can be brought into the circuit, with a consequent change in the resistance of the circuit. A fixed resistance is shown diagrammatically in Fig. 170.

The Complete Circuit

Fig. 171 shows a complete circuit diagram, B being an accumulator, R a variable resistance, A an ammeter, and K a plug key. When the key K is closed, a current flows from the positive terminal of the accumulator, through the circuit and back to the negative terminal. When the slider of the variable resistance is pushed to the left, a shorter length of wire is in the circuit. In this case, the resistance in the circuit is decreased and the current is increased. When the slider

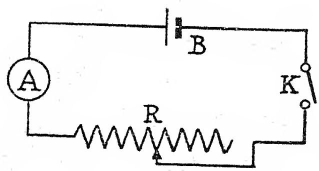


Fig. 171.
COMPLETE CIRCUIT.

is pushed to the right, more wire is included in the circuit, the resistance is increased and the current decreased.

Connecting Wire

To connect the various coils, plug keys, etc., in an electric circuit, copper connecting wire is used. This wire is generally about 0·9 mm. in diameter (S.W.G. 20 to 22) and is cotton covered. The cotton covering insulates the wire from any other conductor with which it may be in contact, causing the current to traverse the whole length of the wire. In using a piece of wire for connecting two terminals, the ends must be bared.

CHAPTER XVII

MAGNETISM AND ELECTRO-MAGNETISM

MAGNETISM

THE PROPERTIES OF MAGNETS

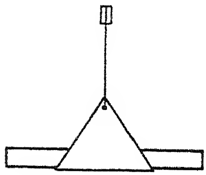


FIG. 172.
BAR MAGNET SUSPENDED IN STIRRUP.

EXPERIMENT L

Suspend a bar magnet in a paper stirrup, supported by a silk thread (Fig. 172). When the magnet has ceased vibrating, it rests with its length pointing in a definite direction, which is approximately north and south.

The end of the magnet facing the north is called the North pole, and the end facing the south the South pole.

EXPERIMENT LI

Suspend a bar-magnet in a stirrup, as in Fig. 172, and allow the magnet to come to rest. Bring the N pole of another magnet near the N pole of the suspended magnet. Repulsion takes place. Now bring the S pole of the magnet near the N pole of the suspended magnet. Attraction takes place. Repeat the experiment, bringing in turn the N and S poles of the magnet near the S pole of the suspended magnet.

The experiment shows that like poles repel each other and unlike poles attract each other.

EXPERIMENT LII

Suspend a piece of soft iron wire in a paper stirrup. Bring the N pole of a bar magnet near one end. Attraction takes place. Now bring the S pole of the bar magnet near this end, and attraction takes place again.

Thus either pole of a magnet attracts a piece of soft iron.

EXPERIMENT LIII

Support a bar magnet (about 6″ long) vertically in a stand (Fig. 173). Place a rod of soft iron (about 2″ long and $\frac{1}{8}$″ diameter) in contact with one pole. The iron rod clings to the magnet. Suspend pins from the

rod as shown in the diagram. Now remove the rod from the magnet and the pins fall off.

This experiment shows that a rod of soft iron becomes a magnet when placed in contact with a bar magnet, and loses its magnetism when it is removed from the magnet. The end of the iron rod, in contact with the N pole of the bar magnet, becomes an S pole and the more remote end of the rod becomes an N pole.

These poles are produced in the iron rod by the influence of the bar magnet and are said to be induced poles. The soft iron rod is said to be magnetised by induction and the magnetism acquired is known as induced magnetism.

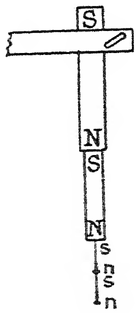


FIG. 173.
IRON ROD MAGNETISED BY INDUCTION.

EXPERIMENT LIV

Prepare a coil, about 20 cm. long and consisting of about 150 turns, by winding ordinary connecting wire round a hollow cardboard cylinder (about 1 cm. in external diameter). Connect the coil in the electric circuit, as shown in Fig. 174, where C is the coil, B an accumulator, R a variable resistance, and K a plug key. Now place a steel knitting needle, about 20 cm. long, in the coil and insert the plug key, so as to complete the circuit. After the current has run for a time, withdraw the needle and insert each end in turn in iron filings. Filings are attracted and form a cluster at each end of the rod. This shows that the needle has become magnetised. Now insert a rod of soft iron (approximately 20 cm. long and 3 mm. in diameter) in the coil, so that one end of the rod projects beyond one end of the coil. Start the current in the circuit, by inserting the plug key, and allow the free end of the rod to rest in a tray containing iron filings. Filings cling to the end of the rod. Now discontinue the current by withdrawing the plug key, when nearly all the filings fall off the rod.

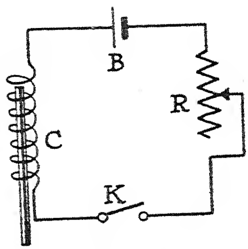


FIG. 174.
IRON ROD MAGNETISED BY A COIL OF WIRE CONVEYING A CURRENT.

TEMPORARY AND PERMANENT MAGNETISM

From the above experiment, it will be seen that steel retains its magnetism after the current has been switched off. This shows that

the magnetism acquired is permanent. In the case of soft iron, however, the magnetism acquired is temporary, since it only lasts as long as the current runs through the coil.

Magnetic and Non-magnetic Substances

Experiment LV

Select a number of wires, composed of different materials, e.g., aluminium, copper, lead, iron, tin, nickel and steel, and place each wire in turn in the coil (Fig. 174), with one end projecting from one end of the coil. Switch on the current in each case and test the wire with iron filings, while the current flows through the coil. Clusters of filings will cling to the end of the wire, in the case of iron, steel and nickel, whereas the other wires are unaffected.

Iron, steel and nickel can be magnetised and are known as magnetic bodies. Aluminium, copper, lead and tin cannot be magnetised and are called non-magnetic bodies.

Magnetic Fields

A magnet not only exerts an attractive force at its surface, but also at points removed from the magnet. The sphere of influence of the magnet is known as the magnetic field due to the magnet.

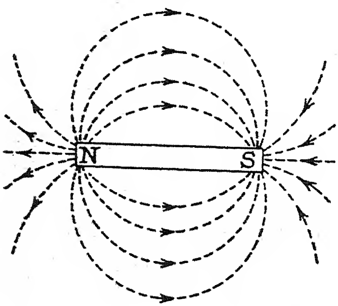


Fig. 175.
LINES OF FORCE OF A BAR MAGNET.

Lines of Force

A line of force is the path along which an isolated North pole, free to move, travels in a magnetic field (Fig. 175). The direction of travel is the positive direction of the line.

Experiment LVI

Place a small compass needle near the N pole of a bar magnet NS, which rests on a sheet of paper (Fig. 176), and mark the ends of the needle n and s. Move the compass needle so that its S pole is near the

mark n and again mark the end n. Continue this process and join all the points until the line of force is completed. Plot other lines of force until the complete field is obtained. Mark the positive direction of each line of force by an arrow.

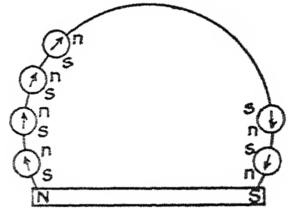


FIG. 176.
TRACING OF A LINE OF FORCE.

ELECTRO-MAGNETISM

In Experiment LIV it was seen that a long coil of wire conveying a current magnetises a bar of soft iron. Thus the coil has a magnetic field associated with it.

Lines of force due to a long coil of wire, conveying a current, are shown in Fig. 177. The thick lines represent the near side of the coil and the direction of the current is shown by arrows thereon. A compass needle, brought near each end of the coil in turn, shows that one end is a N pole and the other is a S pole.

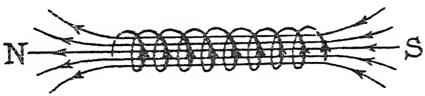


FIG. 177.
LINES OF FORCE DUE TO A COIL CONVEYING A CURRENT.

The polarity of the ends may be determined from the following rule. Look directly at one end of the coil. If the current is counter-clockwise, this end is a North pole. If the current is clockwise, the end of the coil is a South pole.

THE ELECTRO-MAGNET

Fig. 178 shows an electro-magnet. A soft iron core, shaped like a letter U, is wound with cotton-covered copper wire. The winding and the direction of the current are so arranged that the left end of the soft iron core becomes a North pole and the right end a South pole.

We have seen that the magnetism acquired by soft iron is only temporary. Thus the soft iron core is only a magnet during the time the current passes through

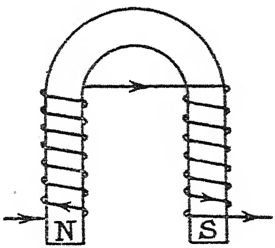


FIG. 178.
ELECTRO-MAGNET.

the coil. The importance of this fact is shown in the electric bell, in which the electro-magnet plays an important part.

The Electric Bell

Fig. 179 shows an electric bell in plan and side elevation. The dimensions of the different parts are indicated in the diagram. X is the soft iron core of the electro-magnet, $\frac{1}{4}$ inch in diameter and bent into a U shape. Y and Z are wooden reels, round which a few hundred turns

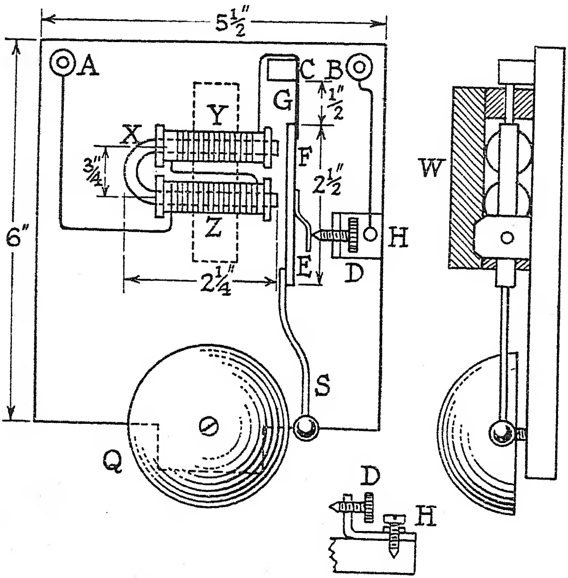


Fig. 179.
ELECTRIC BELL.

of thin insulated copper wire (S.W.G. 30) are wound, so as to produce an N pole at one end and an S pole at the other end. The reels are held in position by a wooden keeper W, screwed to the base board. A piece of clock spring G is fixed at one end to an angle bracket C and a soft iron plate F is soldered to the other end. To this plate are soldered the metal striker S and a strip of clock spring E, bent as shown.

D is a contact screw, connected to the same brass plate as a screw terminal H, which secures the plate to the base board. A and B are screw terminals and Q is the bell.

The ends of the insulated wire of the electro-magnet are connected to the screw terminal A and the angle bracket C. The screw terminals B and H are also connected by a short piece of ordinary connecting wire.

Thus a current which enters at the terminal A passes through the coils of the electro-magnet, to the angle bracket C. The current then travels through the spring G, the soft iron plate F, the spring E and the contact screw D, to the screw terminal B. When no current is passing the spring E rests against the contact screw D. When a current passes, the soft iron core of the electro-magnet attracts the soft iron plate F, causing the bell to be struck. The strip of clock spring E leaves the contact screw D and the circuit is broken. The electro-magnet now ceases to attract and the spring G causes the soft iron plate to resume its original position. The circuit is again completed and the bell rings again.

The Telephone

The telephone consists essentially of the transmitter or microphone A and the receiver B (Fig. 180). In the microphone there is an ebonite

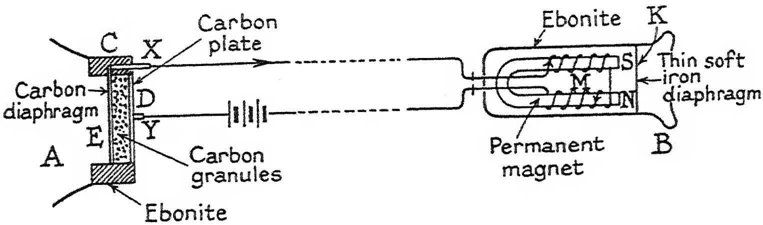


Fig. 180.
TELEPHONE.

cylinder C which is closed by a carbon plate D and a thin carbon diaphragm E. This cylinder contains a quantity of loosely fitting carbon granules. Leads connect the terminals X and Y, through a battery of cells, to the permanent magnet M of the receiver and the coils round this magnet are wound so as to increase its magnetisation. The magnet is enclosed in an ebonite case and a thin diaphragm K, of soft iron, is placed near the poles.

The sound waves from the speaker set the carbon diaphragm of the microphone in vibration. These vibrations alter the mean distance between the carbon granules and consequently the resistance of the

microphone is varied. The resulting variations in the current produce corresponding variations in the magnetisation of the permanent magnet M and the soft iron diaphragm K is set in vibration. In this manner the sound waves which enter the microphone are transmitted to the ear, placed near the receiver.

The Magnetic Crane

Electro-magnets, attached to cranes, are used in iron works for raising large masses of iron. Such a magnet is shown in section in Fig. 181(*a*). A circular coil XY is embedded in the soft iron cylinder A

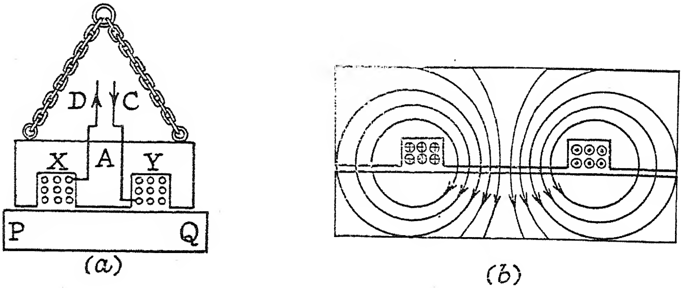


Fig. 181.
(*a*) magnetic crane, (*b*) lines of force.

and the current is conveyed to and from the coil by the leads C and D. The iron cylinder becomes a magnet which is capable of lifting the block of iron PQ from one position to another.

Motion of a Coil, conveying a current, in a Magnetic Field

Experiment LVII

Assemble the apparatus shown in Fig. 182. N and S are the poles of a strong electro-magnet. X is a thick copper rod, supported as nearly parallel as possible to the line joining the poles of the electro-magnet. Y is a piece of thick copper wire which is looped at the upper end, the loop resting on one end of the rod X. This piece of wire should hang vertically between the poles N and S. One end of a piece of thin flex is soldered to the lower end of the wire Y and the other end of the flex is connected to the positive terminal of an accumulator B. The negative terminal of the accumulator is connected, through a variable resistance R, to a terminal Z, fixed to the rod X.

Start the experiment with all the variable resistance in the circuit. In this case the current is practically zero. Then increase the current by moving the slider quickly along the resistance. Note that the wire Y moves across the magnetic field between the poles N and S.

Interchange the terminals of the accumulator and repeat the experiment. Note that the wire Y moves in the opposite direction. Evidently the starting of the current causes the wire Y to move across the magnetic field.

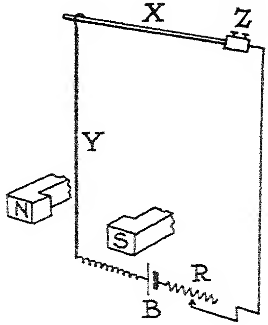


FIG. 182.

APPARATUS TO ILLUSTRATE THE PRINCIPLE OF THE ELECTRIC MOTOR.

FLEMING'S LEFT-HAND RULE

The direction of motion of a wire, conveying a current, in a magnetic field may be deduced as follows: Hold the first finger of the left hand, the second finger and the thumb mutually at right angles to one another. If the first and second fingers represent the directions of the magnetic field and the current respectively, the thumb will represent the direction of motion.

THE MOVING COIL GALVANOMETER

Fig. 183 represents a moving coil galvanometer. N and S are the shaped poles of a permanent magnet. A cylinder of soft iron (not shown in the diagram) is mounted centrally between the poles, with its axis at right angles to the plane of the paper. The effect of this arrangement is to produce a radial field. AB represents one side of a rectangular coil, mounted on a spring, the opposite side being mounted on an exactly similar spring (not shown in the diagram). The coil, which consists of several turns of fine insulated copper wire, is free to move in the space between the poles and the soft iron cylinder. If the current enters at the terminal X, it is then conducted through the spring, through the coil, and out again by the back spring to the terminal Y.

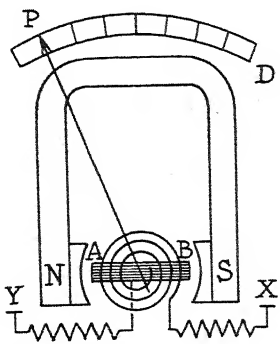


FIG. 183.

MOVING COIL GALVANOMETER.

Suppose the coil is in the position shown, when no current is passing. When a current comes up the left-hand side of the coil at A, by the Left-Hand Rule, the coil rotates in a clockwise direction. A pointer P, fixed to the coil, moves along the scale D. The springs, by unwinding as the deflection increases, act as a control and the coil acquires a position of equilibrium.

A moving coil galvanometer, with a suitable shunt wire across XY, becomes an ammeter.

PRODUCTION OF A CURRENT BY THE MOTION OF A CONDUCTOR ACROSS A MAGNETIC FIELD

EXPERIMENT LVIII

In this experiment, the apparatus shown in Fig. 184 is used. XYZW is a small wooden frame (shown in plan and section) on which are wound about 40 turns of copper connecting wire (S.W.G. 20). The ends of the wire are connected to the terminals P and Q, fixed to the frame.

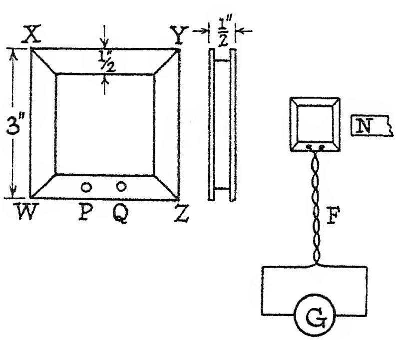


FIG. 184.
APPARATUS FOR SHOWING INDUCED CURRENTS.

To perform an experiment, support a strong bar magnet (12″ long) in a stand. Connect the terminals of the coil to the terminals of a sensitive galvanometer, such as the one shown in Fig. 183, by a piece of flex F. Hold the coil in the hand at about one inch from the N pole of the magnet. Now move the coil quickly towards the magnet, so as to enclose the pole. Lines of force are cut and the galvanometer needle is deflected. Note the direction of this deflection. Move the coil quickly in the opposite direction, when a deflection in the reverse direction will be noticed. Repeat the experiment with the S pole of the magnet.

The experiment shows that when a wire which forms part of a complete circuit is moved so as to cut the lines of force of a magnetic field, a current flows in the wire. The direction of the current is given by Fleming's Right-Hand Rule.

FLEMING'S RIGHT-HAND RULE

If the thumb, the first finger and the second finger of the right hand are held mutually at right angles to one another, and if the thumb and

first finger represent the directions of motion and magnetic field respectively, then the second finger represents the direction of the induced current (Fig. 185(*a*)).

The Left-Hand Rule which gives the direction of the motion due to a current is illustrated in Fig. 185(*b*).

To help the student to remember which rule to use, the following mnemonic may be employed. The student will already know that the

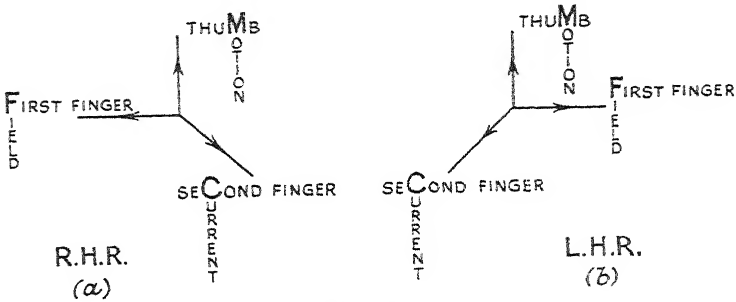


FIG. 185.
(*a*) RIGHT-HAND RULE, (*b*) LEFT-HAND RULE.

motion of the coil of a dynamo produces a current and that a current passed into a motor produces motion. Take the four words: left, right, motor and dynamo. The clue centres round the letter R. Arrange the words in pairs so that each pair contains an R. Thus,

LEFT	MOTOR
RIGHT	DYNAMO

THE DYNAMO

Fleming's Right-Hand Rule is applied to the dynamo, which is a machine for generating an electric current. Fig. 186 shows a coil xyzw, rotating about an axis AB in the plane of the paper, and cutting across the lines of force between the poles N and S of an electro-magnet. As xy moves out of the plane of the paper, by the Right-Hand Rule, a current flows from y to x in xy and from w to z in zw. After half a revolution of the coil, xy and wz exchange places and the current now flows from x to y in xy and from z to w in wz. Thus after every half revolution of the coil, the current is reversed in direction and is known as an alternating current.

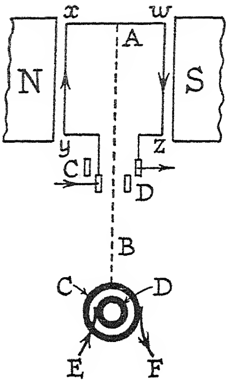


FIG. 186.

ALTERNATING CURRENT DYNAMO.

It can easily be seen that when the coil is connected to the external circuit, the lead wires will become knotted unless some means are available for preventing this. Copper slip rings C and D, insulated* from each other, are connected to the coil and revolve with it on the same spindle. A diagrammatic view of the slip rings is also shown. Carbon brushes E and F which rest lightly on these rings serve to convey the current to and from the external circuit.

Direct Current Dynamo

To obtain a direct current it is necessary to reverse the current every half revolution. This is effected by means of a split ring commutator, which consists of a copper ring cut into two halves P and Q (Figs. 187(*a*) and (*b*)). A section through the ring at right angles to the axis of rotation is also shown. The two portions of the ring, P and Q, insulated from each other, are fixed to the coil and revolve with it. In Fig. 187(*a*), if the current is flowing from y to x, it leaves the coil by the brush Y and enters by the brush X. When the wire xy takes up the position previously occupied by wz, the current in the coil is reversed (Fig. 187(*b*)), but careful examination of the figure will show that the current is in the same direction in the external circuit. When the coil is at right angles to the field, i.e., when the current is changing its direction in the coil, the brushes rest on the gaps between P and Q. Thus the current in the external circuit is always kept in the same direction. In practice several coils are mounted on a rotating frame, known as the armature, and in this way the above effect is multiplied.

In a current-generating machine, the revolution of the

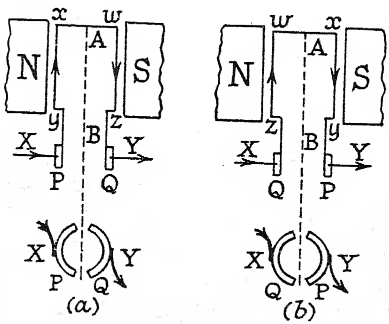


FIG. 187.

DIRECT CURRENT DYNAMO.

* See Chapter XVI.

coil produces a current in the external circuit according to the Right-Hand Rule. If, however, a current is sent into the machine by means of another generator, the coil would revolve according to the Left-Hand Rule. Such a machine would then become a motor.

Exercises XVII

1. What is meant by "lines of magnetic force" and how can they be traced? Two bar magnets are placed end to end on a table in a straight line, but not touching each other. Show how the lines of force are distributed in the space between the magnets (*a*) when both N poles point in the same direction, (*b*) when they point in opposite directions.

(C. G. L. I.; Hand. S.)

2. Describe a simple form of apparatus which can be used in measuring the strength of an electric current and explain the strength of an electric current and explain the principles on which it works.

(C. G. L. I.; Hand. S.)

3. Explain how it is possible to demonstrate experimentally (*a*) the production of an electric current by means of a coil of copper wire and a bar magnet, and (*b*) the production of a magnetic field by means of a coil of copper wire and a battery. Describe the practical application of one of these effects.

(C. G. L. I.; Hand. S.)

4. What is the function of each constituent of a complete electric circuit?

Describe experiments to show that an electric current can cause the motion (*a*) of a piece of iron free to move, (*b*) of another electric conductor.

(C. G. L. I.; Hand. S.)

5. What is meant by saying that electricity is a form of energy? Give, with necessary details, two examples of other forms of energy being transformed into electrical energy.

(C. G. L. I.; Hand. S.)

6. Describe one form of microphone. Explain its action in an ordinary telephone receiver. Give necessary diagrams.

(C. G. L. I.; Hand. S.)

7. How would you construct in a workshop a model that will produce an alternating current?

How may the finished model be tested?

(C. G. L. I.; Hand. S.)

8. Explain what is meant by "electro-magnetic induction," and describe an important application of this principle.

(C. G. L. I.; Hand. S.)

9. Describe, illustrating your answer with suitable sketches, the action of an electric motor.

(C. G. L. I.; Hand. S.)

10. Describe the construction and action of a moving coil galvanometer.

Why are the readings of this instrument unaffected by the earth's magnetic field?

(C. G. L. I.; Hand. S.)

CHAPTER XVIII

OHM'S LAW AND THE HEATING EFFECTS OF CURRENT

Potential Difference

Fig. 188 shows how the pressure varies from point to point along a horizontal tube, through which water is flowing. AB is the horizontal tube, fitted with branch tubes C, D, E, F, etc. To the end A, a reservoir R is connected. The flow of water is produced by the difference in level between the surface of the water in the reservoir and the end B. The pressures at various points in the horizontal tube gradually decrease from A to B. This is shown by the gradual decrease in the heights of the water columns in the tubes F, E, D and C.

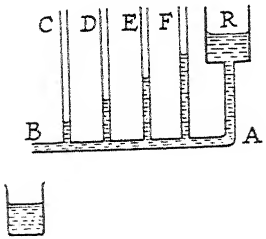


Fig. 188.

FALL OF PRESSURE ALONG A TUBE CONVEYING A CURRENT OF WATER.

The flow of electricity in a conductor such as a copper wire is analogous to this, being due to a difference of electric pressure between the ends of the conductor. This difference in electric pressure is produced by connecting the ends of the conductor to a cell or current generator.

Difference of electric pressure is known as Potential Difference (P.D.). Potential difference is measured in volts by an instrument called a voltmeter.

Current

The quantity of electricity which passes a given point in a conductor per second is analogous to the quantity of water which passes a point in a tube per second. The quantity of electricity flowing per second is known as current strength. Electric current strength is measured in amperes by an instrument known as an ammeter.

Ohm's Law

Ohm's Law is stated as follows:—

The potential difference between the ends of a conductor is directly proportional to the current flowing in the conductor.

If AB (Fig. 189) represents a wire, I the current flowing through the wire, and V the P.D. between A and B, then

$$\frac{V}{I} = \text{a constant}$$

The value of the constant is known as the electrical resistance. Thus we have:—

$$\frac{V}{I} = R$$

where V = the P.D. between A and B, measured in volts,
I = the current flowing, measured in amperes,
and R = the resistance of the wire, measured in ohms.

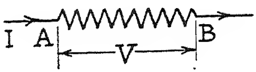


FIG. 189.
OHM'S LAW FOR A CONDUCTOR.

If V = 1 volt and I = 1 ampere, then R = 1 ohm. That is, a P.D. of 1 volt maintains a current of 1 amp. in a conductor of resistance 1 ohm.

RESISTANCES IN SERIES AND PARALLEL

Fig. 190(*a*) shows two resistances arranged in series and Fig. 190(*b*) shows two resistances arranged in parallel. In the case of the resistances

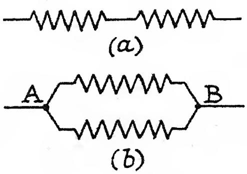


FIG. 190.
RESISTANCES (*a*) IN SERIES, (*b*) IN PARALLEL.

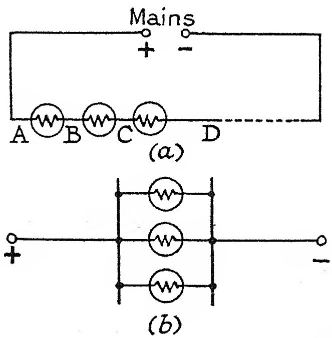


FIG. 191.
ARRANGEMENT OF LAMPS (*a*) IN SERIES, (*b*) IN PARALLEL.

in series, the value of the current is the same in each resistance, whereas in the case of the two resistances in parallel the main current splits up

into two portions at A, which recombine at B. The following example will illustrate this point.

Example. Twenty lamps, each of 1,000 ohms resistance, are arranged (*a*) in series, (*b*) in parallel, across the mains, the P.D. between the terminals being 230 volts. Find the current in each lamp, in each case. (Figs. 191(*a*) and (*b*).)

(*a*) Considering each lamp, we have:—

$\frac{V}{I} = R$, where V is the P.D. between the terminals of each lamp, I the current flowing and R the resistance of the lamp.

$$\therefore V = IR = I \times 1{,}000 \text{ volts.}$$

Thus the P.D. between A and B = 1,000 I volts,

and the P.D. between B and C = 1,000 I volts,

and the P.D. between C and D = 1,000 I volts, etc.

Hence the total P.D. = 20 × 1,000 I volts

$$\therefore 230 = 20 \times 1{,}000\, I$$

$$\therefore I = \frac{230}{20 \times 1{,}000} = 0{\cdot}012 \text{ amp.}$$

(*b*) Considering each lamp, we have

$$\frac{V}{I} = R$$

$$\therefore V = IR$$

$$\therefore 230 = I \times 1{,}000$$

$$\therefore I = \frac{230}{1{,}000} = 0{\cdot}23 \text{ ampere.}$$

In this case each lamp is connected directly across the mains, and takes 0·23 ampere. The total current taken by all the lamps is therefore 20 × 0·23 amperes, i.e., 4·6 amperes.

It must be remembered that the ordinary connecting wire, which is used for joining up the different components of a circuit, offers a resistance to the current. But this resistance is nearly always so small compared with the resistance of the coils that it can be neglected.

Ammeters and Voltmeters

Since an ammeter is an instrument used for measuring the current in a circuit, it must be placed in series with the other resistances. Its function is to measure the current and therefore its resistance must be

very small, so as not to affect appreciably the strength of the current in the circuit.

A voltmeter measures the potential difference between two points of a circuit, and hence it must be placed in parallel with the portion of the circuit between the two points. Thus if the P.D. between A and B (Fig. 192) is required, a voltmeter is connected as shown. The current splits up into two portions at A, which recombine at B. To keep the current in AB appreciably the same, whether the voltmeter is present or not, the voltmeter must have a very high resistance.

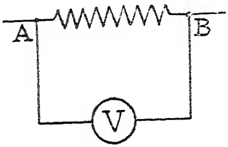


FIG. 192.
VOLTMETER IN AN ELECTRIC CIRCUIT.

Ammeters of the moving coil type have been discussed in Ch. XVII. A moving coil voltmeter is constructed on similar lines, except that a high-resistance coil is placed in series with the moving coil.

CELLS

THE SIMPLE CELL

When plates of copper and amalgamated zinc (i.e., zinc coated with mercury) are placed in a vessel containing dilute sulphuric acid without touching, the arrangement constitutes a simple cell. A potential difference of 1 volt is set up between the plates and, when joined by a wire, a current flows from the copper to the zinc outside the cell.

LOCAL ACTION

If the zinc plate is not amalgamated bubbles of gas appear on the plate. This is due to the action of the dilute sulphuric acid on the zinc and its impurities which form minute cells with the sulphuric acid and the zinc is rapidly consumed. If, however, the plate is covered with a thin coating of mercury, this rapid consumption of the zinc is prevented.

POLARISATION

The voltage of a simple cell rapidly decreases because of polarisation. Polarisation is due to the collection of hydrogen bubbles on the copper plate. These bubbles have the effect of (*a*) reducing the effective surface for the current to enter, and (*b*) sending a reverse current through the cell. To remove the hydrogen, a depolarising agent such

as potassium permanganate is added. The depolarising agent supplies oxygen which oxidises the hydrogen, converting it into water.

The chemical action in a simple cell can be represented as follows:—

Sulphuric Acid + Zinc = Zinc Sulphate + Hydrogen, appears at the copper plate.

The Daniell Cell

The Daniell cell (Fig. 193) consists of a porous pot A which is placed inside a copper vessel B, fitted with a screw terminal T_1. The porous pot contains dilute sulphuric acid, in which is immersed an amalgamated zinc rod C, fitted with a terminal T_2. In the space between the porous pot and the copper vessel copper sulphate solution is poured. When the two terminals T_1 and T_2 are joined by a piece of copper wire, a current flows from the copper (+ve terminal) to the zinc (—ve terminal) outside the cell and from the zinc to the copper terminal inside the cell.

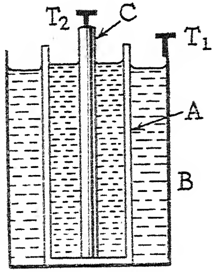


FIG. 193.
DANIELL CELL.

The chemical reactions are as follows:—

Zinc + Hydrogen sulphate = Zinc sulphate + Hydrogen
(Sulphuric acid)

The hydrogen would cause polarisation but for the presence of the copper sulphate solution. Depolarisation takes place as follows:—

Hydrogen + Copper sulphate = Hydrogen sulphate + Copper
(Sulphuric acid)

The copper is deposited on the copper vessel and the copper sulphate solution becomes gradually weaker.

The Daniell cell has a very high resistance and its voltage is about 1 volt. Its use in practice is limited, however, and it has been superseded by the accumulator and the dry cell.

The Leclanché Cell

A Leclanché cell (Fig. 194) consists of a glass vessel A, which contains a porous pot B, the space between being nearly filled with a solution of commercial ammonium chloride (i.e., sal-ammoniac). An amalgamated zinc rod C, connected to a thick wire, is placed inside the solution. The porous pot contains a mixture of gas carbon and manganese dioxide,

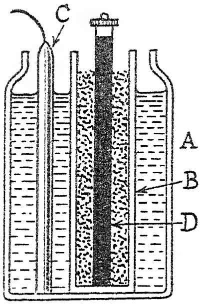


FIG. 194.
LECLANCHÉ CELL.

which surrounds a carbon rod D, fitted with a screw terminal. When a wire connects the carbon and zinc rods, a current flows from the carbon to the zinc, outside the cell. The action of the ammonium chloride on the zinc produces hydrogen, which passes through the porous pot and is oxidised by the manganese dioxide.

The Leclanché cell, whose voltage is about 1·47 volts, soon runs down, owing to the fact that hydrogen is produced more rapidly than it can be disposed of. It is a very useful cell, however, when small intermittent currents are required, as in the case of the electric bell circuit.

ELECTROLYSIS

A glass vessel (Fig. 195) contains a saturated solution of copper sulphate, and two copper plates, fitted with terminals, are immersed in the solution so as not to touch each other. The terminals are connected through a battery of accumulators, a variable resistance and an ammeter and, by adjusting the variable resistance, a suitable current is registered in the ammeter. The current enters the plate A, known as the anode, passes through the solution and leaves by the plate C, the cathode. The glass vessel, the copper plates and the solution constitute a copper voltameter or an electrolytic cell and the solution is known as the electrolyte. If the plates are weighed before and after passing the current for some time, the cathode and the anode show a gain and a loss of weight respectively.

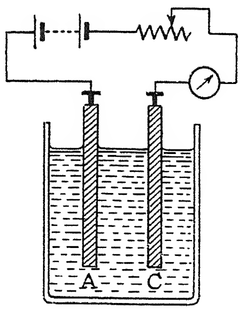


FIG. 195.
COPPER VOLTAMETER.

The chemical changes which take place in the cell are rather involved. In effect, the current passes through the solution from the anode to the cathode and copper is deposited on the cathode. The anode, being composed of copper, serves to replenish the copper sulphate with copper.

THE ELECTROLYSIS OF WATER, ACIDULATED WITH SULPHURIC ACID

Fig. 196 shows the electrolytic cell which is used in the electrolysis of water, acidulated with sulphuric acid. The leads X and Y pass through

a rubber stopper in the base of the vessel B which contains the electrolyte. A and C are platinum electrodes, A being the anode at which the current enters and C the cathode at which the current leaves the cell. Two graduated tubes P and Q which are filled with the electrolyte are supported over the electrodes. Oxygen collects in the tube P and hydrogen in the tube Q. The volume of the hydrogen is double that of the oxygen.

The electric current passes from the anode to the cathode through the electrolyte and, since both the gaseous constituents of water are collected, the cell is sometimes called a water voltameter.

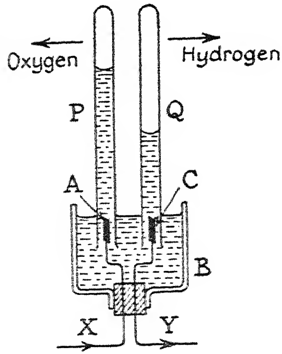


FIG. 196.
WATER VOLTAMETER.

Practical Applications of Electrolysis

Electroplating in industry is carried out in large voltameters called plating vats. The object to be electroplated, known as the "work," is the cathode and the anode is a plate of the metal to be deposited. In copper plating, the electrolyte is copper sulphate solution and the anode is a plate of copper. In silver plating, the anode is a silver plate and the electrolyte is a double cyanide of potassium and silver, whereas in nickel plating the anode is a nickel plate and the electrolyte a solution of nickel sulphate.

In actual practice many precautions have to be taken for good electroplating. The object to be plated must be cleaned, as the presence of impurities does not allow the metal to adhere to the surface. Correct composition and concentration of the electrolyte combined with correct strength of current are essential for the best results.

The Accumulator

Experiment LIX

Connect up the apparatus as shown in Fig. 197. B is a battery of accumulators, R a variable resistance, A an ammeter, and XYZ a two-way switch. E and F are lead plates immersed in dilute sulphuric acid, contained in a glass vessel. An electric bell is connected across the lead plates in the manner shown. Connect X and Y by means of the switch. A current flows through the acid. Allow the current to flow for a few minutes and then switch over the key from XY to XZ. The bell

rings and continues to ring for a short time. The main circuit has been broken at XY and a new circuit through XZ has been produced. The lead plates together with the acid constitute a skeleton accumulator which supplies the current required to operate the electric bell.

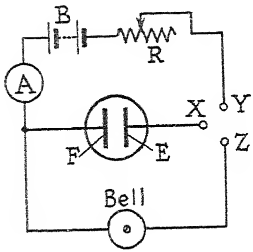


FIG. 197.
CHARGING AND DISCHARGING OF AN ACCUMULATOR.

The above experiment shows the principle of the accumulator. During charging, a current is passed from the battery B through the accumulator from F to E. When the charging current is broken, however, a reverse current flows from E to F through the sulphuric acid. F is the positive plate and the current flows from this plate to the negative plate E, through the bell.

The chemical changes, which occur in charging and discharging an accumulator, are rather involved. When the plates are fully formed, the positive plate is covered with lead dioxide which has a brownish colour, whereas the negative plate is composed of pure lead and is slate coloured. During discharge, both plates become covered with lead sulphate, which has a greyish colour. On recharging, the lead sulphate on the positive plate is again converted into lead dioxide and that on the negative plate into pure lead.

During discharge, the relative density of the acid falls from 1·27 to 1·20. The cell is then ready for recharging. The voltage of an accumulator also falls from 2·1 volts on full charge to about 1·8 volts on discharge.

The accumulator, prepared in the above experiment, only supplies a current for a short time. In actual practice, lead-dissolving acid is added to the sulphuric acid and the charging and recharging are repeated a large number of times. This is the method known as the Planté process. In this process, the depth of the deposit is increased and the plates are said to be "formed."

The quantity of electricity which can be taken from an accumulator without excess discharging is known as its capacity. Thus an accumulator with a capacity of 60 ampere hours is capable of supplying $\frac{1}{2}$ an ampere for 120 hours, 1 ampere for 60 hours, 2 amperes for 30 hours, etc., bearing in mind that there is a safe upper limit to the current which can be drawn from it.

ELECTROMOTIVE FORCE (E.M.F.)

Consider two vessels A and B, connected by a tube, in which a tap T is inserted (Fig. 198). Suppose the vessels contain water, the level in A being higher than that in B.

If the tap T is closed no water flows, but if open the level in A falls and that in B rises. In order to keep a constant difference in level, a pump P draws water out of B and delivers it into the vessel A. A cell functions in a similar manner. We may imagine A and B to represent the positive and negative plates of the cell respectively, and the difference of the water levels, when T is closed, to represent the electromotive force of the cell. The tap T is analogous to the external circuit and the

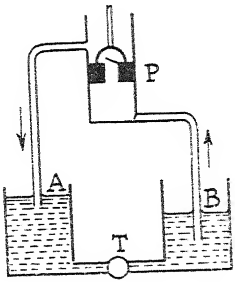


FIG. 198.

MODEL TO ILLUSTRATE THE ELECTROMOTIVE FORCE OF A CELL.

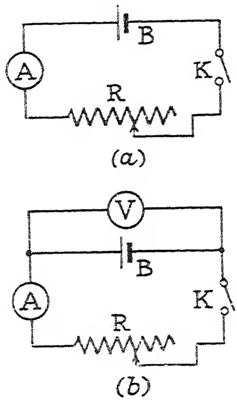


FIG. 199.

OHM'S LAW FOR A COMPLETE CIRCUIT.

pump P to the chemical energy of the cell which causes the current to flow from the negative to the positive plate, inside the cell.

The analogy can be carried still further. If the tap T is only slightly open, it corresponds to a high resistance in the external circuit, in which case a small current flows. If, however, the tap is fully open, it corresponds to a low external resistance and in this case a large current flows.

Fig. 199(*a*) shows a cell B in series with an ammeter A, a variable resistance R and a plug key K. If E is the E.M.F. of the cell, a portion of this E.M.F. is required to drive the current through the external resistance and the remainder drives the current through the cell. Thus:—

E.M.F. of cell = P.D. to drive the current through the external resistance + P.D. to drive the current through the cell

$$\text{i.e., } E = IR + Ir,$$

where I is the current, R the external resistance, and r the internal resistance of the cell.

Fig. 199(*b*) shows the same circuit with the addition of a voltmeter across the terminals of the cell. When the plug key K is withdrawn, the voltmeter measures the E.M.F. of the cell. When the plug key is inserted, the voltmeter only measures the P.D. between the ends of the external resistance.

Example. The terminals of a battery, of E.M.F. 4 volts and internal resistance 1 ohm, are connected to a coil of resistance 10 ohms. Find the current in the circuit and the potential difference between the terminals of the battery.

$$\text{Total resistance of circuit} = \text{External resistance} + \text{Internal resistance}$$

$$= 10 \text{ ohms} + 1 \text{ ohm}$$

$$= 11 \text{ ohms.}$$

$$\text{But } \frac{\text{E.M.F.}}{\text{Current}} = \text{Total resistance}$$

$$\text{i.e., } \frac{4}{\text{I}} = 11, \text{ where I is the current in amperes.}$$

$$\therefore \text{I} = \frac{4}{11} \text{ amp.}$$

$$= 0{\cdot}364 \text{ amp.}$$

Also P.D. between terminals of battery

$$= \text{Current} \times \text{External Resistance}$$

$$= 0{\cdot}364 \times 10 \text{ volts}$$

$$= 3{\cdot}64 \text{ volts.}$$

Heating Effects of Current

It is a familiar fact that heat is produced when an electric current passes through a wire. Notable examples of this are the electric radiator, the electric kettle, the electric lamp, etc. To maintain a current in a conductor, a supply of energy is required. Thus, when the ends of a conductor are connected to the terminals of a cell, a current flows through the conductor. The energy required to maintain this current is the stored-up energy of the cell. This energy is transformed into heat, which appears in the conductor.

The Joule

The unit of energy is the joule. A *Joule* is the energy consumed when a potential difference of one volt maintains a current of one ampere in a conductor for one second.

Thus, if V volts is the P.D. between the ends of a conductor, and I amperes is the current maintained, the energy consumed per second is VI joules. Hence in t seconds, the energy consumed is VIt joules.

i.e., $W = VIt$, where W is the energy consumed in joules.

Also, since $V = IR$ (Ohm's Law)

$\therefore W = I^2Rt$, where R is the resistance of the conductor in ohms.

When energy is consumed, an equivalent amount of heat appears. Now one calorie is equivalent to 4·18 joules. Hence we have:—

$$H = \frac{I^2Rt}{4 \cdot 18},$$ where H is the heat developed in calories.

Power

The rate at which energy is transformed in a circuit is known as the power of the circuit. The unit of power is the *Watt.*

$$\text{Since } W = VIt$$

$$\therefore \text{Power} = \frac{W}{t} = VI$$

i.e., Watts = Volts × Amperes.

A larger unit of power is the Kilowatt, which is equivalent to 1,000 watts.

Example. An electric lamp is marked 60 watts and 230 volts. Find the resistance of its filament.

Watts = Voltage × Current

i.e., $60 = 230\,I$, where I = the current in amps.

$$\therefore I = \frac{60}{230} \text{ amp.}$$

$$= 0{\cdot}261 \text{ amp.}$$

$$\text{Also Resistance} = \frac{\text{Voltage}}{\text{Current}}$$

$$= \frac{230}{0{\cdot}261} \text{ ohms.}$$

$$= 881 \text{ ohms.}$$

The Board of Trade Unit

Electrical energy, as we have seen, is measured in joules. The joule is rather a small unit of energy. A larger unit is the Board of Trade Unit (B.O.T. unit) which is the energy consumed in a circuit in 1 hour when the power is 1 kilowatt.

$$\text{Thus 1 B.O.T. unit} = 1{,}000 \left(\frac{\text{joules}}{\text{seconds}}\right) \times 3{,}600 \text{ (seconds)}$$
$$= 3{,}600{,}000 \text{ joules.}$$

Example. A workshop is lighted with 60 lamps in parallel, each lamp taking 0·4 ampere at 220 volts. Calculate the energy consumed during a working week of 48 hours. Also find the cost of the energy at 2d. per B.O.T. unit.

$$\text{Energy consumed per lamp} = 220 \times \cdot 4 \times 48 \times 60 \times 60 \text{ joules.}$$
$$\therefore \text{Energy consumed by 60 lamps} = 220 \times \cdot 4 \times 48 \times 60 \times 60 \times 60 \text{ joules.}$$
$$= 253\cdot 35 \text{ B.O.T. units.}$$
$$\text{Cost of Energy} = 253\cdot 35 \times 2 \text{ pence}$$
$$= £2 \text{ 2s. 3d. approximately.}$$

Electric Lamps

If a potential difference is applied to the ends of a wire, a current flows in the wire. If the potential difference is gradually increased, the current and consequently the heat developed per second (viz., $\cdot 24 I^2 R$), also increases. This produces an increase in the temperature of the wire. If the wire is composed of a metal with a very high melting point, such as tungsten or platinum, the temperature can be made to increase to such an extent that light is emitted. At first the wire emits heat radiations, then dull red light, then bright red light and, when the temperature is sufficiently high, the radiations emitted are composed chiefly of white light.

This is the principle on which modern electric lamps are based. To obtain white light, the substance must not melt or disintegrate before the temperature necessary for these radiations is reached. That is why metals with high melting points are used.

Again at high temperatures these metals oxidise, combining with the oxygen of the air to form oxides. One of the methods of preventing this oxidation is to evacuate the bulb which contains the wire or filament, as it is called. This is done by means of the diffusion pump shown in Fig. 113. But in a vacuum metals volatilise, that is, turn into vapours if

the temperature is sufficiently high. Consequently, to obtain very intense white light it is necessary to enclose the filament in a bulb containing some inert gas such as nitrogen or argon which reduces this volatilisation to a minimum.

Fig. 200(*a*) shows a tungsten lamp with the filament enclosed in an evacuated bulb. AB is a glass rod with radial supports for the filament and XY are the leads. The filament is wrapped round each support in turn, in the manner shown.

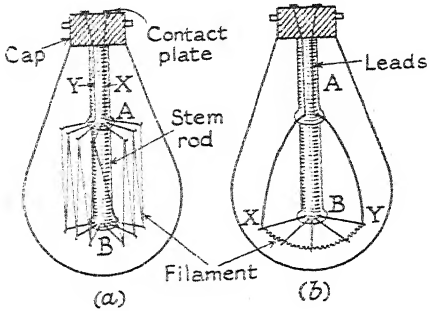


FIG. 200.
(*a*) TUNGSTEN VACUUM LAMP, (*b*) GAS-FILLED TUNGSTEN LAMP.

Fig. 200(*b*) shows a gas-filled tungsten lamp, which is provided with a glass rod AB, from which project the radial supports for the filament. The filament is in the form of a coil XY, the ends of which are connected to the leads which pass through the glass support.

FUSES

The heat developed when an electric current passes through a wire varies as the square of the current. If the current is very large, the heat developed is correspondingly great. Some of the heat generated is conducted away or radiated from the surface of the wire and the remainder raises the temperature of the wire. If the current is not too large, for any particular wire of definite dimensions and material, a steady temperature is reached, for which the heat generated per second is equal to the heat conducted and radiated away per second. If, however, the current is greater than a certain value, a steady temperature cannot be attained, because the temperature rises to the melting point of the material and the wire fuses.

The maximum current which a wire will carry depends mainly on its diameter, the material of which it is composed and the condition of its surface. Thus if we have two wires of the same material and surface conditions, but of different diameters, the thicker wire will carry more current than the thinner one. Again if we have two wires of the same diameter and surface conditions but composed of different materials, the one, composed of the material with the higher melting point,

will carry more current than the other without becoming unduly heated.

Thus it can be seen that for a material such as copper, of moderately high melting point, the current may be sufficient to raise the copper to the steady temperature already mentioned. In the case of the wiring circuit of a building, this steady temperature may be so high that damage to the insulation may be caused.

Again the current may become large enough to raise the temperature of the copper to its melting point and a breakdown may occur, possibly at a point difficult to locate.

To prevent these excessive currents (overloading), circuits are provided with safety devices which consist of wires of definite diameter

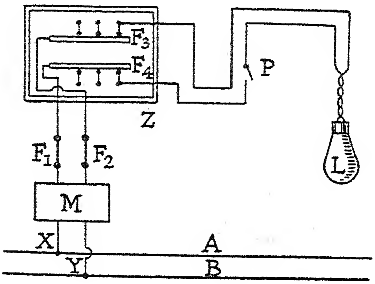


FIG. 201.

WIRING SYSTEM OF A BUILDING.

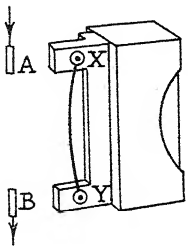


FIG. 202.

FUSE WIRE IN PORCELAIN HOLDER.

and material. These wires, which will carry only a limited current, are known as fuses and are placed in a fuse box (or distributing box) which is easily accessible. Thus, if the circuit breaks owing to too much current (or overloading), it breaks at the fuse.

Fig. 201 shows the wiring circuit of a building. A and B are the underground cables, which consist of thick wires. The current leaves the cable at X and passes through the meter M, which registers the quantity of electricity used. From the meter it passes through the main fuse F_1 to the distributing box Z, through the fuse F_4, the switch P, the lamp L, and back to the distributing box. The current then passes through a second fuse F_3, through a second main fuse F_2, and back to the cable at Y, by way of the meter.

The distributing box Z contains the fuses of the various circuits in the building, and the breaking of one circuit has no effect on the others. The main fuses F_1 and F_2 serve as an additional safety device.

Fig. 202 shows a familiar type of porcelain fuse holder. X and Y are

strips of copper, fitted with terminals, which are connected by fuse wire. A and B are copper-lined slits, into which the fuse holder is inserted.

We have seen that the melting point is a very important consideration in the choice of the material for a fuse wire. For small currents, tin or an alloy of tin and lead is generally used. Copper, which has a much higher melting point, is used for large currents.

Exercises XVIII

1. Six lamps, each of 1,000 ohms resistance, are arranged (*a*) in series, (*b*) in parallel, across the mains, whose potential difference is 240 volts. Calculate the current in each lamp in each case.

2. The terminals of a battery are connected by a wire, the resistance of which is 12 ohms. If the resistance of the battery is 1 ohm and its E.M.F. is 4 volts, what is the strength of the current in the circuit?
(C. G. L. I.; Hand. S.)

3. If the potential difference at the terminals of a lamp is 240 volts and it absorbs 60 joules per second, find (*a*) the current, and (*b*) the effective resistance of the lamp.

4. For what purposes are the following units used: the volt, the watt, the ampere, the ohm? State the relationship between them. If an incandescent lamp is marked 60 watts, 220 volts, what is the current that should pass through it?
(C. G. L. I.; Hand. S.)

5. Illustrate, by reference to the components of an electric bell circuit and of a simple lighting circuit, the effects that may be produced by a current of electricity. Point out any transformations of energy that occur.
(C. G. L. I.; Hand. S.)

6. Weighed zinc and copper plates are placed parallel to one another in dilute sulphuric acid and their upper edges joined by a piece of copper wire. After a short time the plates are taken out of the liquid, carefully dried and again weighed. What is the probable result and in what way is it important?
(C. G. L. I.; Hand. S.)

7. Explain the meaning of each term in Ohm's Law. Outline a series of experiments which would be likely to demonstrate the correctness of the law.
(C. G. L. I.; Hand. S.)

8. What is the practical unit of (*a*) current, (*b*) resistance, (*c*) power? A current of 7 amperes flows for half a minute through a resistance of 30 ohms. How many joules will be produced?

(C. G. L. I.; Hand. S.)

9. State the law relating the flow of an electric current in a conductor to the potential difference between the ends of the conductor.

An electric iron for use on a 240 volt d.c. supply takes a current of 1·8 amps. What is the resistance of the heating element in the iron?

(C. G. L. I.; Hand. S.)

10. Describe and explain the method used in the electroplating of metal objects.

(C. G. L. I.; Hand. S.)

11. What is the essential difference between a primary and a secondary cell? State clearly what should be done to keep a battery of secondary cells in good service condition, and in what ways that condition would be indicated.

(C. G. L. I.; Hand. S.)

12. An electric kettle containing 3 pints of water at 15°C boils in 8 minutes. Assuming that 25 per cent of the heat is lost, what power is supplied to the kettle in watts, and what is the cost of boiling the water at $1\frac{1}{2}$d. per kilowatt hour? (1 pint = 586 c.c.)

(C. G. L. I.; Hand. S.)

13. Show, by means of circuit diagrams, exactly how you would use (*a*) an ammeter and (*b*) a voltmeter, and explain why it is essential that they should be connected in that particular manner.

(C. G. L. I.; Hand. S.)

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